VOLUME 18 JANUARY, 1930 NUMBER 1

PROCEEDINGS

of

The Institute of Radio Engineers

Form for Change of Mailing Address or Business Title on Page XLVII

Institute of Radio Engineers

Forthcoming Meetings

BUFFALO SECTION
Buffalo, N. Y., January 22, 1930

CINCINNATI SECTION
Cincinnati, Ohio, January 23, 1930

NEW YORK MEETING
New York, N. Y., February 5, 1930

PITTSBURGH SECTION
Pittsburgh, Penna., January 21, 1930

SAN FRANCISCO SECTION
San Francisco, Calif., January 15, 1930

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 18 January, 1930 Number 1

Board of Editors, 1929

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	Pittsburgh, 335 Meyran Ave.	Harmon, Ralph Newton
	Pittsburgh, 211 S. Braddock Ave.	Limb, M. G.
	Wilkes-Barre, 182 So. Hancock St.	Dziadosz, Frank
Rhode Island	Providence, 296 Veazie St.	Passarelli, Harold C.
Tennessee	Memphis, O. K. Houck Piano Co., 103 S. Main St.	Breedlove, H. B.
Texas	Dallas, 425½ Neches St.	Harrison, L. E.
	Dallas, 4008 Wycliff St.	Schoonmaker, C. Granville
	El Paso, 3108 Montana St.	Solis, Alberto, Jr.
	Houston, 2120 Blodgett Ave.	Perlitz, W. H.
Virginia	Dumbarton	Zaun, William J.
Washington	Seattle, 1023 3rd Ave.	Haig, James H.
	Seattle, 2607—2nd Ave.	Merritt, Ronald A.
Wisconsin	Madison, Madison Gas & Electric Co.	Steinike, Edgar Wm.
	Wauwatosa, 498—4th Ave.	Mattern, Ray P.
Australia	Melbourne, Victoria, Navy Office, St. Kilda Road.	Toure, F. B.

Bermuda	Middletown	Cadwallader, Carl
Canada	Drummondville, Que., Marconi Station	Smith, Thomas F.
	St. Lambert, Que., 67 Pine Ave.	Hudon, G. F.
	Toronto, Ont., 121 Clovelly Ave.	Foster, Leonard
	Toronto 12, 82 Hillsdale Ave. West	Fraser, D. M.
	Toronto, 21 Slade Ave.	Hanna, Samuel
	Toronto, 21 Melgund Road	Maurer, G. P.
	Toronto, 31 Glebe Road, West	Smith, Clarence M.
England	Derbyshire, Stancliffe Hall, Nr. Matlock	Franklin, T. Bedford
	Teddington, Middlesex, 88 Fairfax Road	Franklin, R. H.
	Llandudno, North Wales, 23 Dinas Road, North Shore "Norvic"	Hughes, Robert Penry
	London W 14, Addison Bridge, 14 Argyll Mansions	Galloway, C. Hadfield
France	Paris, International Standard Elec. Corp., 46 Ave. de Breteuil	Goyder, C. W.
India	Bangalore, Indian Institute of Science, Elec. Dept.	Ashthana, Rajendra, Prasada
Japan	Hokkaido, Sapporo City, Tsukisappu, Sending Station of JOIK	Mori, Nobumitsu
	Sendai, Teishinkyoku, Komuka	Sagiyama, E.
Tasmania	Hobart, University of Tasmania	Tuck, H. P.

For Election to the Junior grade

Alabama	Birmingham, Claridge Manor Apts.	Marshall, Kenneth Glenn Jr.
California	Los Angeles, 332 E. 60th St.	Turner, J. Glen
	Santa Barbara, c o Broadcast Station KDB	Lewis, Evan J.
Dist. of Col.	Washington, 1900 F St. N. W.	Black, Joel Cantrell
	Washington, 4314 River Road, N.W.	Davies, Donald G.
	Washington, 1929 Pa. Ave. N. W.	Eschinger, Earl Edmond
	Washington, 525 Oglethorpe St. N. W.	Hall, Albert Casper
	Washington, 1124—12th St. N. W.	Hedrick, Phil F., Jr.
	Washington, 1430 Belmont St. N. W	Hollingsworth, Edward
	Washington, 1321 D St. N. E.	Rigney, William M.
	Washington, 1330 L St. N. W.	Sprague, Barbara Russell
Illinois	Chicago, 7645 Sheridan Road	Slechta, George W.
Maryland	Berwyn	Parker, Maury McLeod
Massachusetts	Oxford, Main St.	Browning, Elliott Andrew
New Hampshire	Durham, 37 Madbury Road	Evans, Carl B.
New York	Brooklyn, 1569 Ocean Ave.	Haas, Milton J.
	Brooklyn, 2265—85th St.	Mitwol, David
	Corona, L. I., 102-27—47th Ave.	Schubert, Fred
	New York City, 514 E. 138th St., Bronx	Weiler, Harold
	Utica, 1622 Sunset Ave	Howlett, Charles, Jr.
North Carolina	Durham, 1506 W. Chapel Hill St.	Underwood, Norman B.
Ohio	Cleveland, 3585 W. 49th St.	Stanik, Joseph M.
Oregon	Portland, 6904 52nd St. S. E.	Harden, Edgar
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DELEGATES TO THE EASTERN GREAT LAKES DISTRICT CONVENTION HELD IN ROCHESTER, N. Y., ON NOVEMBER 18-19. The above picture was taken at the factory of Valley Appliances, Inc., which was visited on one of the inspection trips.

INSTITUTE NEWS AND RADIO NOTES

Employment Service to Members

During the past several years the Institute office has endeavored to secure positions for Institute members. The Board of Direction of the Institute at a recent meeting decided that this service should be expanded in order to serve the membership more effectively.

Beginning with the February, 1930, issue an advertising page of "Engineers Available" will be published. This page will be available to members of the Institute only. In it will be listed the qualifications of members seeking employment, including age, education, past experience, and an indication of the nature of work desired. Members interested in placing an advertisement in this section should communicate with the Secretary of the Institute for a copy of the employment form. Advertisements will be published at cost, $2.00 per insertion per month.

Forms for this advertising page will close on the 20th of the month preceding the date of publication. That is, as an example, the Institute office must receive the "employment form" properly filled in by the 20th of January for insertion in the February issue.

December Meeting of Board of Direction

A meeting of the Board of Direction of the Institute was held on December 4, 1929, in the Institute office, 33 West 39th Street, New York. The following Board members were present: J. H. Dellinger, acting chairman; Melville Eastham, treasurer; John M. Clayton, secretary; R. A. Heising, J. V. L. Hogan, L. M. Hull, R. H. Manson, and R. H. Marriott.

The Board transferred Colonel A. G. Lee to the grade of Fellow in the Institute, and J. A. Willoughby and J. B. Coleman to the grade of Member.

Ninety-nine Associate and ten Junior members were elected.

J. C. Jensen, of Nebraska Wesleyan University, was appointed alternate to J. H. Dellinger, as the Institute's delegate to the annual meeting of the American Association for the Advancement of Science, held in Des Moines, Iowa, in the latter part of December.

Civil Service Examination for Assistant Inspector

The U. S. Civil Service Commission announces an open competitive examination for the position of assistant inspector (radio enforcement), $2,400 a year salary, to be held at a number of civil service boards throughout the U. S. Members interested in making application for the examination should communicate with their local postmaster or the United States Civil Service Commission, Washington, D. C., referring to the above title, requesting form 2600. Applications must be filed with the Commission by not later than *January 21, 1930.*

Institute Meetings

Eastern Great Lakes District Convention

On November 18th two hundred and fifty Institute members assembled at the Sagamore Hotel, Rochester, to take part in a two-day District Convention, the first of its kind ever held by the Institute.

The program included three inspection trips to manufacturing plants in Rochester, the presentation of seven technical papers, a banquet, an exhibition of parts from some forty radio manufacturers, and provided an opportunity for members to meet each other and engage in frequent lengthy and informal discussions.

The convention was an entire success, due to the splendid cooperation between the Rochester, Toronto, Buffalo-Niagara, and Cleveland Sections of the Institute. A good portion of the work involved in organizing and carrying on the convention fell upon the Rochester Section members who were ably assisted by the Rochester Engineering Society, particularly the executive secretary of the latter, O. L. Angevine.

The program was as follows:

Sunday, November 17th: registration.

Monday forenoon: registration; opening technical session, including address of welcome, by Earl C. Karker, chairman, Rochester Section; "What Engineers Expect of Executives," by I. G. Maloff, Valley Appliances, Inc; "Considerations in Screen-Grid Receiver Design," by W. A. MacDonald, Hazeltine Corporation.

Monday afternoon: inspection trip to Kodak Park and Valley Appliances, Inc.

Monday evening: "Television with Cathode Ray Tube for Receiver," by V. Zworykin, Westinghouse Electric and Manufacturing Co., and "Ultra High-Frequency Transmission and Reception," by A. Hoyt Taylor, Naval Research Laboratory.

CHAIRMEN OF THE EASTERN GREAT LAKES DISTRICT CONVENTION COMMITTEES

These members were responsible for the direction of the work of the several committees of the recent District Convention of the Institute in Rochester, N.Y.

From left to right, standing, are: H. E. Gordon, finance committee; A. R. Barfield, secretary of the section; A. L. Schoen, chairman, trips committee; A. E. Soderholm, chairman, registration committee; E. C. Karker, chairman, entertainment and reception committee; L. Grant Hector, vice-chairman, executive committee; R. A. Hackbusch, chairman, publicity committee; Howard Brown, entertainment and reception committee; A. T. Haugh, toastmaster at banquet.

Seated from left to right: I. G. Maloff, chairman, exhibits committee; R. H. Manson, Board of Directors, Rochester Section; Virgil M. Graham, chairman of executive and technical papers committees; V. G. Smith, registration committee; Harvey Klumb, chairman, finance committee.

There are missing from this picture J. A. Victoreen, chairman of the fellowship committee; J. Eichman, chairman, transportation and accommodation committee; Mrs. O. L. Angevine, chairman, ladies' entertainment committee, and O. L. Angevine, registration secretary.

Tuesday morning: "A Broadcast Receiver for Use in Automobiles," by Paul O. Farnham, Radio Frequency Laboratories; "Standardization in the Radio Vacuum-Tube Field," by W. C. White, Research Laboratory, General Electric Company; "New Developments in Direct Coupled Amplifiers," by E. H. Loftin and S. Y. White, Loftin-White Laboratories.

Tuesday noon: joint luncheon with Rochester Engineering Society; speech by W. Roy McCanne, Stromberg-Carlson Telephone Manufacturing Company.

Tuesday afternoon: inspection trip to Stromberg-Carlson plant.

Tuesday evening: banquet at Sagamore Hotel; Arthur Haugh, toastmaster; "The Engineer in the Radio Industry," by H. B. Richmond, president, Radio Manufacturers' Association; short talks by prominent Institute members.

A special program for the ladies included luncheon at the Blarney Stone Inn, a bridge, dinner at the Sagamore Hotel, theater party at the Eastman Theater, a shopping tour, and a trip to many places of interest in Rochester. This program was arranged by a committee under the able direction of Mrs. O. L. Angevine.

Addresses Before Sections by Arthur Thiessen

During the month of November, Arthur Thiessen, of General Radio Company, Cambridge, Mass., presented a paper, "Accurate Testing of Audio Amplifiers in Production," before eight sections of the Institute. The meetings were arranged as follows:

Toronto Section in Electrical building, University of Toronto, November 13th. V. G. Smith, chairman of the section, presided. Seventy-nine members of the section and their guests attended the meeting. The paper was discussed by Messrs. Parson, Laurie, Hackbush, Angus, Patience, and others.

Buffalo-Niagara Section at the University of Buffalo, November 14th. L. Grant Hector, chairman of the section, presided. Fifteen members of the section were present. The paper was discussed by Messrs. Lidbury, Henderson, Chamberlain, and Hector.

Detroit Section, November 15th. Sixty members were present. No report received.

Cleveland Section, at Case School of Applied Science, November 20th. Bruce W. David, chairman, presided. Thirty-five members of the section were present.

Cincinnati Section at the Cincinnati Club, November 19th. R. H. Langley, chairman, presided. Fifty members of the section and their

guests were present. Messrs. Langley, Felix, Kilgour, Roberts, Austin, and Richmond participated in its discussion.

Pittsburgh Section at Utility Hall, Duquesne Light Company, Pittsburgh, November 22nd. L. A. Terven, chairman of the section, presided. The attendance was twenty-two. Messrs. Mag, Koch, Terven, Cunningham, Haller, Allen, Sunnergren, and Stayer discussed the paper.

Washington Section at Continental Hotel, November 25th. C. B. Jolliffe, chairman of the section, presided. Thirty members attended the meeting. Messrs. Robinson, Stewart, Jolliffe, and others discussed the paper.

Connecticut Valley Section at Springfield, Mass., November 29th. No report received.

Los Angeles Section

At a business meeting of the Los Angeles Section, held in November, the following officers of the section for the 1930 season were elected: chairman, T. C. Bowles; vice-chairman, James M. Chapple; secretary-treasurer, Charles S. Breeding.

Members of the Board of Direction of the section were elected as follows: chairman, T. F. McDonough; B. M. Fox, A. J. Edgecomb, H. W. Anderson, and the officers of the section ex officio.

New Orleans Section

The New Orleans Section held a meeting on November 23rd at Tulane University, New Orleans. Pendleton E. Lehde, chairman of the section, presided.

R. W. French, engineer with the New Orleans Public Service Corporation, presented a talk describing the activities of various public utilities in locating and correcting radio interference caused by their equipment. Statistics were presented showing a percentage of trouble due to various types of equipment, and steps that were taken to correct these troubles were outlined.

Twenty-five members and guests attended the meeting.

New York Meeting

The regular monthly meeting of the Institute in New York City was held on December 4, 1929, in the Engineering Societies Building, 33 West 39th Street, at 7:30 P. M.

Five papers on various phases of aircraft radio problems were presented in fifteen-minute abstracts. The papers were as follows:

1. "Development of the Visual Type Airway Radiobeacon System," by J. H. Dellinger, H. Diamond, and F. W. Dunmore, all of the Radio

Section, Bureau of Standards, Washington, D. C. This paper was presented by Dr. Dellinger and is summarized as follows:

> This paper summarizes the experimental work carried on by the Bureau of Standards on the development of a radiobeacon system for guiding aircraft, using visual course indication. Descriptions are given of the beacon transmitting system (two-, four-, and twelve-course types), the receiving system for use aboard airplanes, and special adaptations of the beacon system for facilitating landing in fog.

It is expected that this paper will be published in a forthcoming issue of the PROCEEDINGS.

2. "Temperature Rating of Wind-Driven Aircraft Radio Generators," by C. B. Mirick, U. S. Naval Research Laboratory, Bellevue, D. C., was presented by Mr. Mirick. The paper was published in the December, 1929, issue.

3. "On the Daylight Transmission Characteristics of Horizontally and Vertically Polarized Waves from Airplanes," by F. H. Drake and R. M. Wilmotte, Aircraft Radio Corporation, Boonton, N. J., was presented by Mr. Wilmotte. The paper was published in the December, 1929, issue of the PROCEEDINGS.

4. "Applying the Visual Double-Modulation Type Radio Range to the Airways," by H. Diamond, Radio Section, Bureau of Standards, Washington, D. C., was presented by the author. This paper was published in the December, 1929, issue of the PROCEEDINGS.

5. "Measurement of Aircraft Antenna Constants," by L. A. Hyland, U. S. Naval Research Laboratory, Belleuve, D. C., was given by the author, and was published in the December, 1929, issue.

In the absence of President Taylor, R. H. Marriott presided at the meeting which was attended by two hundred and fifty members and guests.

PHILADELPHIA SECTION

On December 3rd the regular monthly meeting of the Philadelphia Section was held in The Franklin Institute. R. L. Snyder, chairman of the membership committee of the section, presided.

Two papers were presented as follows: "A Summary of Progress in the Study of Radio Wave Propagation Phenomena," by G. W. Pickard and G. W. Kenrick, and "Ions in the Upper Atmosphere," by E. O. Hulburt. Prof. Kenrick presented the former paper, which is summarized as follows:

A survey from the inception of the art to the present day of radio transmission studies was made. Particular emphasis was placed upon the developments in the subject during the last year, including important developments both in America and Europe. A critical survey of important recent papers on short-wave direction finding and the Kennelly-Heaviside layer was made and their results critically reviewed and discussed. The results of recent as yet unpublished work were also presented.

This paper is to be presented at a meeting of the Institute in New York City on January 8th, and will be published subsequently in the PROCEEDINGS.

The second paper is summarized as follows:

In order to explain the variations in the earth's magnetism the ionization in the levels of the atmosphere from 80 to 150 km is assumed to be predominantly ions, rather than electrons. The ion densities for day and night all over the earth are calculated, and agreement is found with the absorption and downward reflection of the longer wireless waves, as far as the facts are known.

The sunset longitude of the earth comes out to be about 2000 volts positive with respect to the sunrise longitude. Due to the crossed electric and magnetic fields, the ionization above 150 km rises at night. This reduces the rate of disappearance of the electrons in the high atmosphere and secures agreement with the night-time skip distances.

Both papers were discussed by Messrs. Earnshaw, Synder, Goodall, Darlington, and others.

Forty-two members and guests attended the meeting.

ROCHESTER SECTION

Periodically during the past several years the Rochester Section has provided programs for Tuesday noon luncheons of the Rochester Engineering Society during one month of the year. During December, 1929, among other meetings the section furnished luncheon speakers as follows:

December 3, "Present and Future Trends in Radio," by R. H. Manson; December 10, "1917 in St. Petersburg," by I. G. Maloff; December 17, "Eoörnis Pterovelox Gobiensis," by Arthur T. Haugh. It is understood that the latter paper was based upon the extended research of the author and his associates in the Gobi desert.

All of these speakers are prominent in the affairs of the Institute and the Rochester Section.

SEATTLE SECTION

On November 22, 1929 a meeting of the Seattle Section was held in Physics Hall Laboratory, University Campus, at Seattle. Austin V. Eastman, chairman of the section, presided. Sixty-eight members of

the section were present to hear the paper, "Photo-electric Applications," by C. L. Utterbach.

Professor Utterbach opened his talk with a brief explanation of atomic structure, presenting lantern slides illustrating the helium, lithium, and radium atoms. He then explained the action of electrons as pertain to light. The effect of a strong arc light on the electroscope, charged both positively and negatively, was next demonstrated. By means of a very sensitive galvanometer the action of a photo-electric cell exposed to different colors of light was clearly shown. It was shown that the light intensity did not affect materially the emission, but that different wavelengths, or colors, of light did affect the energy of photo-electric current flow.

The speaker next explained the Wein and Raleigh-Jean curves showing the relation of energy to light frequency. From this point Professor Utterback proceeded to explain the quantum and Einstein theories as pertaining to photo-electric emission.

Washington Section

On November 14th a meeting of the Washington Section was held in the Laboratory Room, East Building, Bureau of Standards, Washington, D. C. C. B. Jolliffe, chairman of the section, presided.

C. F. Jenkins presented a paper, "Transmission of Motion Pictures by Radio." The paper was illustrated by lantern slides showing the theory of television and descriptive of the apparatus used by Mr. Jenkins. A historical summary of the development of television, particularly with reference to the work of the author, was given. Mr. Jenkins also discussed the interference caused in the immediate vicinity of a television transmitting station to broadcast receiving stations.

Sixty-four members attended the dinner preceding the meeting and two hundred and ten members and guests were at the meeting itself. The paper was discussed by the following: A. Hoyt Taylor, R. M. Page, G. D. Robinson, and William F. Curtis.

Radio Signal Transmission of Standard Frequency January to June, 1930

The Bureau of Standards announces a new schedule of radio signals of standard frequencies for use by the public in calibrating frequency standards and transmitting and receiving apparatus. The signals are transmitted from the Bureau's station WWV, Washington, D. C. They can be heard and utilized by stations equipped for continuous-wave reception at distances up to about 1,000 miles from Washington.

The transmissions are by continuous-wave radiotelegraphy. A complete frequency transmission includes a "general call," "standard frequency signal," and "announcements." The general call is given at the beginning of each 12-minute period and continues for about 2 minutes. This includes a statement of the frequency. The standard frequency signal is a series of very long dashes with the call letter (WWV) intervening; this signal continues for about 4 minutes. The announcements follow on the same frequency as the "standard frequency signal" just transmitted, and contain a statement of the frequency. An announcement of the next frequency to be transmitted is then given. There is then a 4-minute interval while the transmitting set is adjusted for the next frequency.

Information on how to receive and utilize the signals is given in Bureau of Standards Letter Circular No. 171, which may be obtained by applying to the Bureau of Standards, Washington, D. C. Even though only a few frequencies are received (or even only a single one), persons can obtain as complete a frequency meter calibration as desired by the method of generator harmonics, information on which is given in the Letter Circular. The schedule of standard frequency signals is as follows:

Eastern Standard Time	Jan. 20	Feb. 20	Mar. 20	Apr. 21	May 20	June 20
10:00 PM	1600	4000	550	1600	4000	550
10:12	1800	4400	600	1800	4400	600
10:24	2000	4800	700	2000	4800	700
10:36	2400	5200	800	2400	5200	800
10:48	2800	5800	1000	2800	5800	1000
11:00	3200	6400	1200	3200	6400	1200
11:12	3600	7000	1400	3600	7000	1400
11:24	4000	7600	1500	4000	7600	1500

Committee Work

Committee on Admissions

At the meeting of the Committee on Admissions held on November 29, 1929, in the Western Universities Club, 11 West 53rd Street, New York City, the following were present: R. A. Heising, chairman; E. R. Shute, J. S. Smith, George Lewis, and H. P. Westman. The committee considered eleven applications for transfer or election to the higher grades of membership in the Institute, making favorable recommendations on five. The committee considered the revision of a memorandum prepared by the 1928 committee which has been used as a basis of interpretation of the constitution of the Institute with regard to the

various requirements and qualifications for membership in the higher grades.

Committee on Membership

At the November 6th meeting of the Committee on Membership, the following members were present: I. S. Coggeshall, chairman; F. R. Brick, H. B. Coxhead, H. C. Gawler, S. R. Montcalm, A. F. Murray, J. E. Smith, W. H. Beltz, R. L. Duncan, C. R. Rowe, and A. M. Trogner.

For the benefit of the four new appointees to the committee, the greater part of the meeting was taken up with a review of the committee's activities in canvassing firms for lists of prospects.

The committee outlined future work in securing members from the broadcast, transmitting, and service fields.

Committee on Sections

The Committee on Sections met on December 5, 1929 at 6:30 P. M. in the rooms of the Western Universities Club, 11 West 53rd Street, New York. Those present were: E. R. Shute, chairman; D. H. Gage, F. P. Guthrie, C. W. Horn, C. B. Jolliffe, R. H. Langley, R. H. Manson, Austin Bailey, H. P. Westman, and J. M. Clayton.

The committee reviewed correspondence with members in prospective sections. It carried on a number of routine duties in connection with its supervision of section activities. At the request of the Board of Direction, as a result of extended study of the subject, the committee made recommendations to the Board with regard to certain future section policies and the solution of some present and future section difficulties.

Personal Mention

August Hund, formerly associated with the Radio Section of the Bureau of Standards and more recently travelling in Europe, has returned to the United States and is now associated with Wired Radio, Inc., at Ampere, N. J., in charge of special research.

John F. Morrison, formerly engineer at broadcasting station WKBW, is now connected with the radio development department of Bell Telephone Laboratories in New York City.

John G. O'Connor has resigned from the Radio Corporation of America, where he has been employed as travelling inspector, to join the operating department of Mackay Radio and Telegraph Co. at New York City.

C. J. Paddon, of the engineering department, Electrical Research Products, Inc., is now installation supervisor of the Societe de Materiel Acoustique, Paris, France.

Leo J. Peters, until recently in the electrical laboratory of the University of Wisconsin at Madison, is now associated with the Gulf Oil Co. at Pittsburgh, Pa.

Captain Francis E. Pierce has been transferred from the United States Marine Corps to Field Officers' School, Quantico, Va.

R. P. Roberts has left the Philco Storage Battery Co., of Philadelphia, to become supervisor of electrical inspection of the amplifier department, Audio Vision Appliance Co., at Camden, N. J.

Clarence O. Roser, recent student at the University of Wisconsin, has become connected with the plant supervisor's staff, Wisconsin Telephone Co., at Milwaukee, Wis.

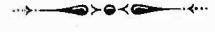
Roscoe Royal is now connected with the design and manufacture of photo-electric and responsive devices. Mr. Royal was formerly telephone engineer at the Hawthorne Plant at the Western Electric Co.

W. J. Schnell has left the All American Radio Corp. of Chicago to become chief engineer of Electrical Research Laboratories of that city.

John S. Starrett, formerly engineer of Nassau Radio Company of Brooklyn, has joined the engineering staff of International Telephone and Telegraph Co. at New York City.

L. W. Wickersheim has been transferred from the toll equipment engineering department, Southern California Telephone Co., at Los Angeles, to toll systems development department, Bell Telephone Laboratories, New York City.

Captain Robert B. Woolverton, Signal Corps, U. S. Army, for several years located at Seward, Alaska, has been transferred to Presidio of San Francisco, Cal., as post signal officer.



Part II

TECHNICAL PAPERS

REPORTS OF I.R.E. COMMITTEE ON BROADCASTING

A Committee on Broadcasting of the Institute of Radio Engineers was established in the fall of 1928 as a means by which the Institute might assist the government as well as the Institute membership in the solution of some of the technical problems involved in the development of broadcasting. Reference to the establishment of this committee appears on page 20 of the 1929 Year Book of the Institute. The members of the committee are: L. M. Hull, chairman; Arthur Batcheller, Carl Dreher, Paul A. Greene, Raymond Guy, J. V. L. Hogan, C. W. Horn, R. H. Marriott, and E. L. Nelson.

Shortly after the committee was organized, the Institute received a request from the then Chief Engineer of the Federal Radio Commission, Dr. J. H. Dellinger, that the Committee study and make reports on certain subjects. The committee proceeded to work along the lines suggested, in accordance with the letter of request, from which the following excerpt is given:

> "The committee can accomplish work of direct value to the Federal Radio Commission as well as of general value to the public by securing and collating engineering information on the following problems. These are roughly in order of urgency.
>
> 1. Requirement of a dummy antenna for use during warming-up period.
> 2. Location of high-power stations with respect to populous areas. My memorandum of October 1st is offered as a basis of discussion.
> 3. Regulation of the experimental development of broadcast station synchronization. A suitable basis of discussion by the Committee would be my memorandum of October 24th, enclosed.
> 4. Permissible deviation of carrier frequency from licensed frequency. The present regulation is given in General Order No. 7. (In this and a number of the other problems it will be desirable to take into account the possible differences of capabilities of the several classes of broadcast stations, and other differences such as simultaneity of identical programs, time division, etc.)
> 5. Allowable ratio of day to night power. This should be considered first with respect to winter conditions; a secondary phase of the problem is the amount of power to be allowed in the summer time, both for day and for night, and possible in the intervening seasons as well, together with the determination of time of beginning and end of these seasons. My memorandum of Oct. 17th enclosed is offered as a basis of discussion.
> 6. Permissible intensity of harmonics and other parasitic radiation intensity.
> 7. Requirement as to percentage modulation, either minimum or maximum. Consideration of possibility of specifying side-band power rather than carrier power.

8. Fidelity of transmission, that is, the degree of accuracy with which the modulation of the radiated wave reproduces the program.

"In addition to the foregoing there are a number of subjects of interest to the Commission, with which your committee is well adapted to deal and upon which definite and comprehensive information is lacking. As subjects for study by the committee for some months to come, I would suggest the following:

I. Effective methods of power rating and radiation measurement.
II. Service area of stations of various powers.
III. Amount of interference at various distances for various amounts of radiation, for stations on the same normal frequencies and for stations separated 10, 20, and 50 kilocycles.

The committee could render a most valuable service in preparing reports from time to time on the state of knowledge of these subjects. This service would be materially enhanced if the Committee's activities could include the bringing about of experimental work by suitable agencies where needed to supplement available data."

The committee has been active during the past year and has now submitted eight reports, which, after approval by the Board of Direction, have been forwarded to the Engineering Division of the Federal Radio Commission. All of the questions on which reports have been made up to the present time relate primarily to the external effect of apparatus used for broadcast transmission. The Committee on Broadcasting has taken the view that while the type of transmission produced, both as to its service aspects and as to its interference aspects, is of important concern to the public and to the Federal Radio Commission, neither the public nor the Commission is directly interested in the mechanism used at the transmitting station for producing these external effects. These reports, therefore, do not go into such questions as apparatus design, circuit details, and methods, but are largely confined to a discussion of the results produced.

The reports of the committee cover subjects of interest to radio engineers, generally and particularly to broadcast engineers, and to those who are interested in the technical problems involved in the proper assignment of frequencies to broadcast stations. The completed reports of the committee follow. Any future reports made by the committee will be published in the PROCEEDINGS after approval by the Board of Direction.

Report No. 1. Requirement of a Dummy Antenna For Use During the Warming-Up Period

For the purpose of this report a dummy antenna is defined as a device having all the necessary characteristics of an antenna with the exception that it radiates in the form of heat instead of in the form of radio waves substantially all the energy fed to it.

The use of dummy antennas has been required as a convenient necessity in the testing of radio apparatus for more than fifteen years. In manufacturing, thousands of radio transmitters have been brought up to the operating point on dummy antennas. For some years radiotelegraph transmitters have fed their power into a dummy antenna when the key was up and into the radio antenna when the key was down.

The cost of a dummy antenna is small in comparison with the cost of a radio transmitter. It may consist of a switch, a condenser, a resistance, an inductance, and insulation. All of this equipment is available on the open market. The owner of a home-made low-power broadcast station can probably make a dummy antenna in keeping with his other equipment for as little as ten dollars. Other operators of broadcast stations will probably pay sums of the order of magnitude of one hundred dollars for a dummy antenna for a 100-watt station, three hundred dollars for a 1,000-watt station, one thousand dollars for a 10,000-watt station, two thousand dollars for a 50,000-watt station.

In many cases effective screening will be necessary; that is, it may be necessary to house the radio-frequency circuits in a cage or room, the walls of which are of good conducting material at practically all points. This will involve some additional cost. In some types of apparatus, it is necessary only to disconnect the radiating system to test without the production of interference radiation, when the apparatus up to that point is screened. Some other forms of apparatus could, if screened, perform the same results if a resistance were inserted in the next to the last radio circuit, a slight shift were made in the inductance, and the antenna and ground disconnected.

With regard to the question of interference produced by a station when operating on a dummy antenna or equivalent, it may eventually be desirable to require that the radiation under these conditions shall not establish a field strength in excess of a specified amount at a given distance. It is not now practical to specify the magnitude of this field strength.*

The outstanding advantage of the dummy antenna to the owner of the broadcast station is that the owner may operate his entire plant at any time for warming-up, testing, substituting parts, varying loads, adjusting frequency, gauging modulation, and otherwise making his station suitable for transmitting.

* Report No. 6, below, deals with this subject.

Therefore it is recommended that:

(1) A station should not radiate in such amount as will cause substantial interference before or after the period assigned for broadcasting.

(2) If preliminary warming-up tests are necessary, these should be made with a dummy antenna, or its equivalent, and with such screening as may be required.

(3) This does not apply to authorized experiments where electrical radiation of the energy is necessary.

(4) A period of three months should be allowed for meeting the above requirements.

Approved by Board of Direction
December 5, 1928.

Report No. 2. Location of High-Power Broadcast Stations with Respect to Populous Areas

This report is directed to the specific problem of establishing the location of broadcast stations in addition to or replacing those already in service. All considerations of interference, useful coverage, etc., herein are definitely limited to that populous or urban area with respect to which the proposed station is to be located.

The committee emphasizes at the outset the fact that from an engineering standpoint every case should be considered on its individual merits. Among the technical factors which enter into such a consideration, the following may be listed: (1) field-intensity pattern due to a transmitter at the proposed station site; (2) location of and coverage provided by other stations in the same area; (3) frequency assignments of all stations in this area including the proposed station; (4) distribution and density of population in this area; (5) performance of the average radio receiver in this area; (6) arbitrary definition of the radio service which the average listener may reasonably expect in this area.

It is realized that in most cases a decision must be reached without complete information on these points. Since it is practically impossible at the present state of engineering development to provide such complete information, the technical recommendations of the committee must necessarily be of the most general sort.

In this report the existing practice of maintaining a frequency separation of 50 kc between local stations is taken as a starting point. Although it is well-known that the attenuation of radio waves in the broadcast band tends to increase with increasing frequency, and

that the selectivity of most radio receivers also depends upon the frequency, it is recommended that in the consideration of the question under discussion no discrimination between stations be made at present on the basis of their relative positions in the broadcast band.

The following recommendation has been made by Dr. Dellinger:

> Every station of 5 kw or more shall be "located at such a place that the radio field intensity at the nearest boundary of a populous center shall not be more than 100 mv per meter." Roughly, this means that stations of the following power must be located at distances not less than those shown beyond the city limits:

Kilowatts	*Miles*
5	2
10	2.8
25	4.5
50	6.3

The committee agrees with the principle of this recommendation, and feels that it may in many instances be reasonably applied to stations of less than 5 kw.

It is noted that no definition of the term "boundary of a populous center" is given in this recommendation. A universally applicable definition of this term for radio purposes is believed to be impossible. In applying this recommendation to specific cases one important consideration may be taken into account. In determining the extent to which the 100-mv or blanketing area may encroach upon a large community the significant figure is not so much the *density* of population in a blanketed region as it is the *ratio* of total population in the blanketing interference area of the proposed station to the total population in the service area of that station. It must be recognized that a certain amount of such interference from any broadcast station is unavoidable at the present state of the engineering art.

With regard further to the above quoted recommendation, it is probable that in certain situations a field intensity greater than 100 mv per meter can be allowed, so far as interference is concerned. This statement recognizes the performance of certain existing stations and performance of modern radio receivers. According to present engineering practice interference should be considered unreasonable when it is produced, in modern radio receivers, by a station separated 50 kc or more from the desired station, where the desired station normally gives consistently good service at the point of observation in the absence of such interference.

It can be stated that the specific figures given by Dr. Dellinger on the minimum advisable distance from the nearest populous center

as related to the proposed transmitter power, while admittedly approximate, are reasonable estimates from the engineering data available at the present time. Appreciable encroachments upon the numerical limits set forth in the above named memorandum should be permitted only in cases where sufficient engineering data are supplied to justify such departures.

It is recommended that applicants for construction permits be encouraged to submit the following information to the Radio Commission:

(1) Location and nominal power of all other broadcast stations which the applicant considers to be serving the same area as the proposed station.
(2) Approximate number of inhabitants within the three areas defined by circles centered on the proposed site and having radii equal respectively to 1 mile, 2 miles, and 5 miles.
(3) A survey of the field intensities established by an experimental transmitter situated at the proposed site. This transmitter may be of low power, but the numerical values of field intensity as submitted should be corrected to correspond to a transmitter power equal to the power proposed for the station. The assumptions made with respect to the antenna in making this correction should be stated. The survey should embrace at least an area bounded by the contour of 100 mv per meter for the corrected field intensities.

Approved by Board of Direction
December 20, 1928.

Report No. 3. Synchronization—Preliminary Requirements for the Conduct of Tests

The discussion which follows is limited to stations which transmit the same program. Since we are concerned primarily with the requirements or limits which should govern experimental operations in a field where there is a scarcity of accurate or systematic data, the principal object is to formulate restrictions allowing useful experiments with the least possible risk.

Methods of Synchronization

Among the possible *methods* of synchronization are the following:

(1) The sending of a control frequency by wire from a single point to each station.
(2) Independent standards in each station:
    (a) Temperature-controlled piezo oscillator;
    (b) Tuning fork and harmonic amplifier.

(3) Broadcast-frequency pickup:
  (a) Manual control;
  (b) Automatic control.
(4) Low-frequency pickup.
(5) High-frequency pickup:
  (a) Beat between two;
  (b) Step up from modulation frequency;
  (c) Step down.

More generally, broadcast transmitters which may for experimental purposes be termed synchronized transmitters fall into two general *classes* as follows:

(I) Two or more transmitters emitting carrier frequencies which are supplied from, or automatically controlled by, the same source.

(II) Two or more transmitters, in each of which the carrier frequency is individually controlled by its own source.

Method (2) applies to systems of class (II), whereas the others, except (3a), are used in systems of class (I), at least in principle.

PRELIMINARY REQUIREMENTS ON SYSTEMS OF CLASS (I).

Systems of class (I), wherein both carriers are automatically controlled from a common source, approach absolute synchronization over long periods. Experiments with systems of class (I) are probably less likely to cause trouble or inconvenience to the listening public than experiments under class (II). Restrictions on method (I) may properly be directed mainly toward the satisfaction of the Commission that this method is actually being carried out. Thus in connection with method (I) the following limitations, or their equivalents, should be imposed:

(1) A common source of frequency shall be provided for the stations. This may be an audio frequency or a radio frequency, depending upon convenience.

(2) Current from the common source must be supplied to the transmitters of all stations engaged, by either wire or radio channel.

(3) Evidence must be supplied to the Federal Radio Commission that the carrier waves emitted by all stations engaged in the experiment are continuously and automatically controlled by frequency of the common source during the periods of transmission.

Under these conditions it is believed that the stations may safely be permitted to broadcast the same program during regular hours, in experimental periods sufficient in the opinion of the Federal Radio Commission to justify the issue of a license.

Preliminary Requirements on Systems of Class (II).

In the opinion of this committee, continuous synchronization is not feasible in systems of class (II) with existing commercial apparatus. It is always possible for a finite difference in frequency to exist between transmitters which are individually controlled. Continuous synchronization may prove to be necessary for satisfactory operation in the future, although conclusive evidence on that point is not yet available. Until the requirements for successful operation are more definitely determined, experiments under the conditions which are associated with class (II) are justifiable.

The following experimental periods have been proposed by Dr. Dellinger:

Experimental Period I.—Observations shall be taken at least every two days over a period of at least two months, to determine whether the standards used are capable of remaining constant in frequency continuously within 15 cycles of the licensed frequency. (See second sentence under *Experimental Period II.*)

At the end of this period, besides the checks already mentioned the Commission may require new calibrations of the standards by the Bureau of Standards.

Experimental Period II.—Next, it is necessary to demonstrate that the emitted waves from the stations can be held continuously within 15 cycles of the licensed frequency. (At some future time it will probably be necessary to restrict this to a smaller variation, but for the present 15 cycles can be allowed, permitting a maximum variation between synchronized stations of 30 cycles.) The trial and demonstration of this shall be a period of not less than one month specified in General Order No. 45. In special cases the Commission may authorize such tests also in the daytime. Observations of the relative frequencies of each station shall be made at a distance greater than one mile from any station at least every two nights for a period of at least two hours.

Experimental Period III.—For a period of not less than one month of transmissions by the stations during the hours after midnight as specified in General Order No. 45* of the Federal Radio Commission (or, in special cases authorized by the Commission, in the daytime), observations shall be made, at least every two nights of the character of received signals from the stations. These observations shall include observations taken at approximately 20, 50, and 100 miles from each station (and in special cases also at other distances specified by the Commission). They shall be made by observing relative signal intensity, fading, quality, and other characteristics of the signals, alternately with all stations operating and with one station operating. The Commission may detail a Government observer to participate in this part of the work.

This phase of the experimental work is of particular importance for the following reason. The results of theoretical studies and of such partial

* Published in Radio Service Bulletin, September 29, 1928.

trials as have been made indicate that, while heterodyne interference will be removed by synchronization, there will be in its place an annoying impairment of the quality and fluctuation of intensity due to a form of interference of the waves from the two stations. While this may not destroy as much of the service area as would heterodyne interference, it will nevertheless reduce the service area of each station. The gain to be expected from synchronization, if and when it is demonstrated, therefore, is that many stations may be placed on one frequency, the sum of their small service areas being greater than the service area of one station if operating alone on the frequency. It is not now known whether this gain will actually be realized. In any event, the service area of a synchronized station may be less than it would have been if it operated alone on the frequency. There may be no service in intermediate areas remote from any of the synchronized stations. The use of only one station on a frequency is likely to continue as the only means of giving service in large rural areas.

Experimental Period IV.—For a period of not less than one month, to be specified by the Commission, the stations shall operate with synchronization with no limitation of hours. Observations similar to those during the *Experimental Period III* shall continue. In addition, the stations, not less than twice each evening, shall announce to the radio audience that they are operating experimentally in synchronization with other stations, naming them, and requesting all persons who notice interference or fading to send a report of their observations to the Commission.

It is the opinion of this committee that these experimental periods are not too restrictive, and are well justified in most cases by the difficulties of obtaining valid general conclusions on the results of transmissions according to method (II).

With regard to constancy of the standard sources, which is to be checked during the *Experimental Periods I and II*, the important point is to maintain these sources at frequencies which depart from each other by less than thirty cycles. If this requirement is fulfilled, the secondary requirement that they be adjusted at the same time to operate, to within the same limits, at the assigned frequency, would appear to be unnecessary. If the primary requirements of synchronization be fulfilled, no further restrictions are required on the absolute value of the carrier frequencies than those set forth in Report No. 4 of this committee.

Experimental operation with stations of this class may demonstrate that these limits are too wide, or even that systems of class (II) are in general unsatisfactory.

It is believed that the proposals under *Experimental Period IV* should be modified to allow the stations to operate with synchronization for not less than one month, and to require that the *observations* be carried on for at least one month. Provision should be made for extending this last experimental period, if desired, for a considerable

time before the Commission issues a license, because it is impossible to specify any particular period as sufficient to allow the collection of conclusive data.

Tests and Conclusions

The proposals under *Experimental Period III* and *Experimental Period IV* outline suitable test procedures and call attention to certain unfavorable results for which the technical observers should watch. It should be emphasized that audio-frequency distortion may occur in the received signal in common service areas of the synchronized stations, even with systems of class (I). With systems of class (II) this distortion may possibly be increased by the occurrence of a beat note between the partially synchronized carriers, even though this beat note be below the normal audible limit. Among the conditions which should be met for ideal operation of synchronized stations of either type, the following may be listed:

(1) No substantial diminution in the individual service areas of synchronized stations.

(2) No interference or distortion in the common service or overlap area.

(3) No disturbance tending to produce cross-talk in any local system of frequency allocations, due to the assignment of the frequency of a distant station to one local station for purposes of synchronization.

With regard to the proposal that broadcast listeners send the Commission reports of their observations on synchronized stations, it is believed that such reports are likely to be misleading from a technical standpoint. It is therefore undesirable to encourage such reports on experiments of this nature, where the results are likely to be complicated by fading and beat-note phenomena which have no connection with the synchronization of the stations under test.

Approved by Board of Direction
April 3, 1929.

Report No. 4. Permissible Deviation of Carrier Frequency from Licensed Frequency

Under any scheme for the intensive utilization of the available broadcast channels such as the existing system of broadcast frequency allocation, accurate maintenance of the assigned frequencies is of primary importance if serious interference, particularly beat-note interference, is to be avoided.

In considering the effects of deviations from the assigned frequencies it is advantageous to distinguish the two important origins of beat notes.

(1) Inter-channel beat notes (those occurring between the carriers of stations assigned to *separate* channels).

(2) Intra-channel beat notes (those occurring between the carriers of stations assigned to the *same* channel).

With the existing system of allocation, the minimum inter-channel beat note under ideal conditions would be 10 kc. The effect of deviations from the licensed frequency is to lower this figure. For example, with the plus or minus 500-cycle deviation permitted under General Order No. 7* of the Federal Radio Commission, one station may be 500 cycles low while the station operating on the next lower channel may be 500 cycles high, resulting in a beat note of 9 kc. Insofar as inter-channel beat notes are concerned, therefore, the question of a revision of the existing regulation resolves itself into a consideration of the improvement to be had by raising the inter-channel beat note from 9 kc to 9.9 kc or some similar figure.

No noteworthy amount of quantitative data concerning the performance of commercial radio receivers and loud speakers in the region between 9 and 10 kc has been published. The evidence that is available, however, points very definitely toward the conclusion that under any conditions likely to be encountered in practice, present-day receiving apparatus is substantially incapable of reproducing beat notes of 9 kc and above. It is unlikely, therefore, that inter-channel beat-note interference is being experienced today unless one or both of the stations involved is operating outside of the 500-cycle limits imposed by General Order No. 7. Insofar as this particular class of interference is concerned there would appear to be no justification for changing the existing regulation.

As a corollary, it follows that with the present 10-kc channel spacing, beat notes on any of the *cleared channels* can be as effectively controlled by strict adherence to the 500-cycle limit specified in General Order No. 7 as by any more rigorous requirement.

The elimination of beat-note interference on the "regional" and "local" channels involves, in addition, the control of intra-channel beat notes. Ultimately, this will probably require a limit on the permissible frequency difference between carriers which will maintain the beat frequency at a value below the audible range. Such performance is not believed to be a practical possibility at the present stage of the art. It can be achieved only by highly refined apparatus, which

* Published in Radio Service Bulletin, April 30, 1927.

is yet beyond the resources of many of the smaller stations that occupy the channels under discussion.

As a temporary expedient, however, there is reason to believe that a considerably larger deviation than that which would be required for sub-audible beat notes can be tolerated, due to the deficiencies of present-day loud speakers and radio receivers, which in general discriminate markedly against the lowest audible frequencies. It is probable, therefore, that a noteworthy improvement in intra-channel beat-note conditions could be brought about on any given channel if the stations assigned to it would maintain their assigned frequency to plus or minus 50 cycles or less.

It cannot be considered a permanent engineering solution to endeavor in this manner to take advantage of a current deficiency in one element of a comprehensive system for the purpose of easing the legitimate requirements imposed on another element in the system. On the other hand, there is no question that the beat-note problem is very serious and that remedial measures are urgently needed. Further, there is no definite indication as to when a more highly refined frequency control system will become available or when a greatly improved reproducing system will be introduced. Also, an effort on the part of the industry to meet a plus or minus 50-cycle requirement, while it may not be a complete solution, and while its effect may only be temporary, will nevertheless serve as a powerful stimulus to the development of the more refined apparatus and improved technique ultimately required.

Careful analysis of the intra-channel beat-note phenomena indicates that the requirements are not as difficult to meet as they may appear at first sight. Leaving out of account the problem of serving a common area from two or more stations all broadcasting the same program, which is another matter, the service area of a regional station in the absence of beat notes is limited by the attenuation and fading or by cross-talk from other stations assigned to the same channel.

With regard to cross-talk, experience indicates that a field-intensity ratio of wanted to unwanted carrier of at least 100:1 must obtain if the entertainment value of the program is not to be seriously affected by the interfering signal.

As to beat notes, if the 100:1 ratio is met and the degree of modulation is in accord with current practice, experiments with a number of the better commercial receivers and loud speakers now available show that the additional attenuation introduced by these devices is sufficient to reduce the intra-channel beat note below the threshold of audibility, provided the beat frequency is less than 100 cycles. It should be noted

that in less favored areas, where the interfering field is greater than 1/100th of the desired field, the beat note may still be plainly evident, but in such areas the value of the program is already irrevocably impaired by cross-talk.

Any scheme for the control of beat notes must take into account frequency modulation effects. Many of the broadcast transmitters in use today consist of a simple vacuum-tube oscillator coupled to the antenna and modulated by superimposing the signal voltage upon the direct voltage impressed on the plate of the tubes. It is well-known that the frequency of power oscillators is affected by changes in plate voltage. Accordingly, modulation in this manner not only results in the desired variation in carrier *amplitude*, but is, in general, also accompanied by corresponding changes in *frequency*, which may amount to plus or minus 1,000 cycles or more. This "carrier wobble" not only prevents any proper control of frequency but often produces interference on adjoining channels and, under certain conditions, promotes serious distortion at relatively distant receiving points. The effect can be avoided by employing a properly designed master oscillator separated from the modulating amplifier by one or more isolating stages. In view of the impairment to service which results from this transmitter deficiency, there appears to be necessity for action on the part of the Commission to require suitable corrective measures quite apart from the matter of beat-note control. In general the devices required at a station for frequency control to plus or minus 50 cycles would automatically eliminate serious "carrier wobble."

The maintenance of frequencies in the broadcast band with a maximum permissible deviation of plus or minus 50 cycles is believed to be both technically and economically feasible, at the present state of the art. The required degree of accuracy and stability can hardly be attained, however, without resorting to automatic frequency control by means of tuning forks, piezo crystals, and similar devices. Such devices must not only be accurately adjusted to the required frequency but should be enclosed in constant temperature chambers. The associated oscillator circuits must be carefully designed and reasonable care must be exercised by the operating staff in maintaining proper values of temperature as well as filament, plate, and grid voltages. The apparatus requirements are not unreasonably severe, however, and are met by apparatus now commercially available. No serious difficulty should be experienced in developing the proper attitude and technique on the part of the station operating staffs, particularly among the "regional" stations, since the responsibility for conditions on each regional channel can be placed entirely on the stations occupying that channel. The

operators should be required to keep written records of significant meter readings taken at regular intervals.

It is probable that most of the stations in the country would be required to make more or less extensive changes in their transmitters to meet a plus or minus 50-cycle maximum deviation requirement. The effort involved is such that sufficient time, probably at least one year, should be allowed to bring the project to completion.

To summarize, the study which the committee has given to this subject has led to the following conclusions:

(1) On the cleared channels the existing plus or minus 500-cycle limit, if adhered to, will practically eliminate beat-note interference to the extent that this is possible with 10-kc channel spacings.

(2) On the regional and local channels there is no worthwhile advantage to be gained by setting up more rigorous requirements unless a maximum deviation of plus or minus 50 cycles or less can be attained.

(3) It is possible that if frequencies assigned to regional and local services were maintained to plus or minus 50 cycles, a noteworthy improvement in beat-note conditions would be brought about.

(4) It is essential in all broadcasting to suppress frequency modulation effects and other short period deviations. A requirement that all stations hold their frequency to plus or minus 50 cycles would be helpful in bringing this about.

(5) A plus or minus 50-cycle limit is feasible with automatic frequency control devices available today, but a period of at least one year should be allowed to enable all broadcast stations to become equipped.

Approved by Board of Direction
January 25, 1929.

Report No. 5. Allowable Ratio of Day to Night Power

This report is directed to the specific question of the desirability and possible effects of increasing in the daytime the transmitter power now assigned to existing stations for night transmission. It should be emphasized that there is little hope of equalizing the day and night service or the summer and winter service from a given station, with any practical diurnal or seasonal alterations in power. Probably the only technical justification for tolerating a daytime increase in power is the general fact that limitations on day power are dictated mainly by

liability to cross-talk interference in regions near the transmitter, while the night power is limited also by heterodyne interference over much wider areas. Thus the recommendations of this report as to the tolerable amount of daytime increase in power should be considered as mainly for the benefit of stations whose coverage includes rural districts, and which are so situated that their interference capability is confined largely to heterodyne interference at night. If a station is so situated and operated that cross-talk with other stations having overlapping service areas is already an important factor, no increase in power by day over the existing level is justifiable. But in cases where the proposed increased daytime power still falls within the limits imposed by Report No. 2, with respect to the location of populous areas, the recommendations stated below may be followed.

The items of Report No. 2 which are significant in this connection are as follows:

"The following recommendation has been made by Dr. Dellinger:

> Every station of 5 kw or more shall be 'located at such a place that the radio field intensity at the nearest boundary of a populous center shall not be more than 100 mv per meter.' Roughly, this means that stations of the following power must be located at distances not less than those shown beyond the city limits:

Kilowatts	*Miles*
5	2
10	2.8
25	4.5
50	6.3

"The committee agrees with the principle of this recommendation and feels that it may in many instances be reasonably applied to stations of less than five kw.

"It is recommended that applicants for construction permits be encouraged to submit the following information to the Radio Commission:

(1) Location and nominal power of all other broadcast stations which the applicant considers to be serving the same area as the proposed station.

(2) Approximate number of inhabitants within the three areas defined by circles centered on the proposed site and having radii equal respectively to 1 mile, 2 miles, and 5 miles.

(3) A survey of the field intensities established by an experimental transmitter situated at the proposed site. This transmitter may be of low power, but the numerical values of field intensity as submitted should be corrected to correspond to a transmitter power equal to the power proposed for the station. The as-

sumptions made with respect to the antenna in making this correction should be stated. The survey should embrace at least an area bounded by the contour of 100 mv per meter for the corrected field intensities."

(1) The Radio Commission may receive applications from stations desiring increase of power during the daytime, subject to regulations embodying the above recommendations. Under the present system of power distribution it is considered advisable to limit the day-night power ratio to a value of 5:1, thus avoiding excessive alteration in field intensity when the decrease from day to night power is effected. A decrease of greater magnitude might be undesirable from the standpoint of listeners.

(2) The results of any such power changes should be studied through field-intensity measurements, reaction of listeners, etc., at various seasons. These observations may ultimately lead to a sliding scale of day-night power ratios based on seasonal variations in the properties of the transmission medium.

The committee endorses from the engineering standpoint General Order No. 53* of the Federal Radio Commission, which provides that in all cases the broadcast station licensed to use a higher daytime power should be compelled to reduce power promptly at the local sunset to the night level.

Approved by Board of Direction
June 5, 1929.

Report No. 6. Permissible Intensity of Harmonics and Other Spurious Radiation

The intensive utilization of the transmission medium is undoubtedly an outstanding technical problem in radio today. In any scheme for doing this it is essential that harmonics and other spurious radiation be effectively controlled. Progress in this direction has been seriously retarded by the absence of recognized performance standards expressed in proper quantitative terms. The interests of the entire industry require that this deficiency be rectified as soon as possible.

The discussion which follows is concerned primarily with harmonics, that is, with frequency components which bear an integral relationship to the assigned carrier frequency. Spurious radiation in other forms is encountered from time to time, but under existing conditions is a much less important factor. Sum and difference terms resulting from parasitic oscillation, unwanted modulation products due to over-

* Published in Radio Service Bulletin, November 30, 1928.

loading, overmodulation or instability, and radiation from artificial antennas may be cited as examples. The control of all such phenomena is a problem which presents numerous ramifications, and the formulation of rigid general requirements should not be undertaken until more quantitative information is available. As a tentative working basis, however, it is thought to be logical to undertake to extend the regulations governing harmonics to cover all radiation outside of the licensed frequency band and the assigned operating period.

The discussion, of course, deals only with interference effects arising from transmitting irregularities. Complaints of harmonic interference are, at times, received by the operators of broadcast stations which can be traced directly to deficiencies in the design of the receivers employed. If a receiver with poorly designed selective circuits is subjected to relatively high local field intensities one of the radio-frequency tubes may be overloaded and may then function as a modulator or harmonic generator, leading to the erroneous conclusion that the received wave is "broad" or contains substantial harmonic components. Such effects would be observed even if an absolutely pure wave were emitted by the transmitting station and, accordingly, can be controlled only by proper action at the receiver.

With present-day vacuum-tube transmitters, the attainment of reasonable power efficiencies requires that the tubes be operated in such a manner that relatively large harmonic voltages are impressed on the output circuits. The problem of the control of harmonics, therefore, resolves itself into the design of suitable selective circuits to attenuate such voltages before they reach the antenna and the provision of adequate shielding to limit direct radiation from coils and connectors. Theoretically, there is no limit to the discrimination that can be obtained in this manner; practically, the expense for apparatus and specific engineering increases rapidly with the degree of suppression required.

At the present time, field-intensity measurements appear to afford the most accurate and convenient method quantitatively determining the performance of a station insofar as harmonics are concerned. It is recommended that for regulatory purposes the requirements relating to harmonics be expressed in terms of harmonic field strengths at a specified distance, say one mile, and of percentages representing the ratio of the intensity of each harmonic to that of the assigned frequency, that is, to the fundamental, at the same distance. Experience indicates that the field-intensity patterns for the various harmonics frequently differ radically from that for the fundamental. Accordingly, the performance of a station cannot be conclusively

evaluated by observations at a single point. It is desirable to determine roughly the field strength contours by taking a series of measurements at approximately equal angles around the station. With a suitable measuring set mounted in an automobile, this is a relatively simple and straight-forward undertaking.

Unless unusual (and possibly unreasonable) precautions are taken there will always be a region immediately surrounding a transmitting station in which harmonics can be detected. The greater the degree of harmonic suppression attained, the smaller this area will be. On the other hand, the cost of the selective circuits required will increase rapidly. The establishment of practical and equitable limits therefore involves a compromise between the value of improved service in this surrounding region and the burden imposed upon the operating organization in bringing about the improvement. Neither of these factors can be computed with accuracy. Under the circumstances, the choice of a suitable limit becomes largely a matter of judgment and experience.

The information in the possession of this committee indicates that at the present stage of the art it is reasonable to limit the harmonics from a broadcast station to 0.05 per cent in terms of field strength. This limit is fairly consistent with the recommended practice with respect to the location of higher powered stations. The harmonic field intensity at the boundary of the populous area which a station is intended to serve should preferably fall below the average noise level at that point. If the fundamental field strength at the boundary is assumed to be 100,000 μv per meter, which is the figure mentioned in Report No. 2, a 0.05 per cent harmonic, neglecting absorption, represents 50 μv per meter. In many urban areas, noise levels of this order of magnitude are regularly encountered.

It is characteristic of a percentage limit that it results in proportionally larger harmonic field strengths as the station power is increased. Thus, if the percentage limit on harmonics be placed at 0.05 per cent, a harmonic field at one mile of the order of 25 μv per meter will be allowed for a station which radiates 50 watts. A 5-kw station under similar conditions would be allowed 250 μv per meter and a 100-kw station 1120 μv per meter. As previously indicated, if the stations are properly located with respect to the areas which they serve, the interfering field will be attenuated with distance to such an extent that at the nearest boundary the field intensities from all stations regardless of their rated output will be approximately the same and below the average noise level. In the case of an exceptionally high power installation, however, where the station is located at some distance from the recognized boundary, a relatively large suburban population may be

subjected to abnormal harmonic fields. Further, as a matter of avoiding potential interference in the high-frequency portion of the spectrum it is considered to be undesirable to permit stations to radiate sufficient harmonic power to establish field strengths of any considerable magnitude. Accordingly, an absolute limit of 500 μv per meter at one mile is suggested.

To summarize, it is recommended that all transmitting stations be required so to limit the field intensities at one mile, of all components which they produce outside of the licensed frequency band and the assigned operating period, that no component shall exceed either 0.05 per cent of the fundamental or 500 μv per meter.

The limits proposed are being met by the more prominent broadcast stations now in operation. These limits are more rigorous than those which are met by a number of the older equipments. A regulation should not be put into effect, therefore, without allowing a period for apparatus improvements commensurate with the magnitude of the changes required and the number of stations involved. An interval of six months is suggested.

If generally applied these limits should improve conditions to a very noteworthy extent. However, in the case of moderately powered stations, which are generally located in the midst of the communities that they serve, there will still be a small area immediately surrounding the station in which the beat-note interference due to the second harmonic may be encountered. For this reason the assignment of neighboring stations in harmonic relationship should be avoided.

Approved by Board of Direction
December 4, 1929.

Report No. 7. Modulation Capability

Although radio broadcasting has won a secure position in our national life, evidence continues to accumulate indicating that the country as a whole is poorly served. It is to be expected, therefore, that improvement in the existing facilities will continue. Since there is little possibility that the boundaries of the present broadcast band can be extended in the face of the overwhelming demand for radio channels for other services, this progress will require more intensive development of that portion of the spectrum now in use. A noteworthy step in this direction has recently been made possible by the introduction of broadcast transmitters capable of a relatively high degree of modulation. This report discusses "modulation capability" from the systems and regulatory standpoints.

The degree of modulation of the carrier in a radiotelephone transmitter is a somewhat intangible factor which necessarily varies rapidly through wide limits during the rendition of a program. With every transmitter, however, there is a definite modulation limit which is a characteristic of the design and which cannot be exceeded without bringing about serious distortion. This limit is an important performance index which, for lack of a better name, has been called "modulation capability." The modulation capability of a transmitter may be defined as the maximum degree of modulation (expressed as percentage) that is possible without appreciable distortion, employing a single-frequency sine-wave input and using a straight line rectifier coupled to the antenna in conjunction with an oscillograph or harmonic analyzer to indicate the character of the output.

For a number of reasons, some technical and some economic, many of the broadcast transmitters in use at the present time have been so constructed that overloading of the audio power stage with consequent distortion occurs whenever the degree of modulation exceeds approximately 50 per cent. The usual practice in placing such transmitters in service consists of determining, by means of a suitable vacuum-tube voltmeter or other "volume indicator," the audio level at the input of the set for which distortion becomes evident. The average operating level is then established at a suitably lower value, frequently as much as 6 db. Recently transmitters have been produced capable of 100 per cent modulation without noteworthy distortion. It is obvious that if a transmitter of this latter type is employed and the same margin is observed in setting the average audio input level, the resulting side bands will have twice the amplitude of those produced by a transmitter whose modulation capability is only 50 per cent. To produce equivalent side bands with a transmitter capable of but 50 per cent modulation requires that the carrier amplitude be doubled, or the carrier power output multiplied by four. In other words, insofar as signal-to-noise ratio is concerned, which is the factor that usually determines the coverage of a broadcast station, the increase in modulation capability mentioned results in an improvement that in the older type of apparatus could only be had by quadrupling the rated output of the transmitter. From a coverage standpoint, the range of a given station can be approximately doubled in this manner. Since this is accomplished without increase in the carrier power, the outlying zone in which the station may produce serious beat-note interference with others assigned to the same channel will not be extended. It is evident, therefore, that the use of transmitters capable of a high degree of modulation is a noteworthy contribution toward intensive development of the available band.

The foregoing discussion has emphasized the advantages of a high degree of modulation from the standpoint of increased coverage without the use of increased carrier power.

It is believed to be feasible without unwarranted expense to increase the modulation capability of existing stations to at least 70 per cent.

It is the opinion of this committee that broadcast stations should be encouraged to increase their modulation capability, and that regulatory action should eventually take advantage of the improvements in engineering technique in this respect which are now generally known.

Approved by Board of Direction
June 26, 1929.

Report No. 9. Effective Methods of Power Rating and Radiation Measurement

Several methods for power rating have been used and recommended. The power rating has usually been intended as a measure of radiation. The defect has been that such power ratings were not accurate measures of effective radiation. Effective radiation is the subject in which a regulatory body is interested. How much power a station owner uses to produce a given effective radiation is only of interest to the owner of the station and not to the regulatory body.

The old method long in use, which consisted of measuring the current in the antenna and the effective resistance of the antenna, indicated the power consumed at the antenna when the current was measured at the right place and when the effective resistance of the antenna was measured without introducing changes other than an actual known change. But the effective radiation was also dependent upon the effective height of the antenna, the effective resistance of the neighboring ground, and the screening effects of the neighborhood. These latter factors were usually estimated; therefore, the effective radiation was in fact only an estimate.

The method of stating the power in meter-amperes also has resulted in estimates. The current in amperes must be measured in the right place, and the effective height in meters has usually been estimated as have been the ground resistances and screening effects.

The simple method of measuring the voltage and current in the last tube of a transmitter, multiplying the voltage by the current and dividing by two, is an approximation similar to that employed in former methods, and is even more of an estimate because it is based on the supposition that one-half of the power from the last tube circuit is transferred to the antenna circuit.

The virtue of this latter volt-ampere method is its simplicity. The present view is, however, that this method would give more nearly the carrier current in the antenna of a broadcast station if one-fourth the volt-ampere product was taken as the power where the last tube is a modern type amplifier tube with a tank circuit between the plate circuit and the antenna. Not measuring the power at the transmitter but measuring the radiation or field intensity at a distance from the transmitter is believed to be the method that will give the surest useful information to a regulatory body relative to stations broadcasting at frequencies between 550 and 1500 kc. This field-intensity method is a better indication of the power that is available to the broadcast listener.

An example of this method is to measure the intensity of the received signals, in μv per meter, at eight equally separated points on a circle about the station five miles distant from the station, average the readings and rate the station in μv-per-meter field intensity at five miles.

If all broadcast stations are measured in this same way a better knowledge of the comparative effects of their carrier waves can be obtained than by present methods.

It is believed that the Department of Commerce will soon be equipped to make such field-intensity measurements on land. Also it is believed that the making of such measurements will soon point out the systems for correcting readings where they cannot all be made at eight equally spaced points five miles from the station.

This field-intensity method can also apply to other stations where the ground-wave service is of primary importance. For short-wave stations where the sky wave is used as in relay broadcasting, this method would only be applicable by measuring the μv per meter on a circle of very large radius and at different seasons and times of day and night.

The mile is a good unit of distance for United States measurements, because automobile road maps and other convenient maps showing practically all localities in the United States are laid out in miles.

Five miles is considered to be a good distance because in some localities low-power stations give a very low reading at greater distances. With a five-mile radius the broadcast station is entirely within the ground-wave distance, eight test points are about four miles apart and the distance around the circle is one that can be covered by an automobile in about two hours. It is recommended that broadcast stations in the band from 550 to 1500 kc be rated in terms of their average field intensities in μv per meter or measured as nearly as practicable at eight points forty-five degrees apart on a circle having a radius of five miles and of which the station is the center.

Pending the time at which stations can be measured in terms of their field intensities, it is recommended that the power of stations using master oscillators and power amplifiers with a tank circuit between the last tube circuits and the antenna be rated as using a power equalling 25 per cent of the volt-amperes in the plate circuits of the last tubes; and that other transmitters be rated as using power equal to 50 per cent of the volt-amperes in the plate circuits of the last tubes.

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THE OPERATION OF MODULATORS FROM A PHYSICAL VIEWPOINT*

By

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Summary—*The mathematical expressions which occur in the treatment of non-linear devices as circuit elements are interpreted in terms of a graphical physical picture of the processes involved. This picture suggests, in turn, several useful ways of applying the equations in cases where the driving forces are so large that the ordinary power series treatment becomes prohibitively cumbersome. In particular, the application has been made in detail to the calculation of the intermediate-frequency output to be expected from a heterodyne detector having an incoming radio signal and locally generated beating oscillator voltage applied on its grid and a circuit of finite impedance to the intermediate frequency attached to its plate.*

In the past it has been customary to deal with circuits containing non-linear resistances by the employment of a power series formulation. It is important to state at the outset the exact scope and limitations to which such a method is subject. The power series itself can be shown to be capable of representing any continuous curve to any desired degree of accuracy. In the special case where the curve possesses an unlimited set of derivatives at some one of its points, a Taylor's series will exist, and this may be used. However, even when no convergent Taylor's series can be found, there exist power series which, when enough terms are taken, represent the given curve to any desired degree of accuracy.

With these facts in mind it is evident that the power series formulation, while of universal applicability to physical problems, involves a tedious computation for any cases except those in which the variable input voltage to the non-linear element, such as a vacuum tube, is so small that only the first few terms of the series are needed.

The present method of treatment was developed in the out-of-hour courses at the Bell Telephone Laboratories in order to provide a basis for handling these more involved cases. This is done by building up physical pictures, so that the alteration of circuit constants and of applied voltages may be visualized, and quantitative results when required may be obtained by straightforward and comparatively simple means. To demonstrate the validity of the physical viewpoint which is applied further on to a special case—the heterodyne detector—

* Dewey decimal classification: R134.

we shall apply the power-series formulation to the case of a two-frequency e.m.f. impressed on a non-linear resistance. By suitably interpreting the resulting equations we arrive at processes which are found to be generally useful.

Starting with the power-series formulation for the static characteristic of a vacuum tube:

$$I = a_0 + a_1 E + a_2 E^2 + a_3 E^3 + a_4 E^4 + \cdots, \tag{1}$$

by inserting the expression for the impressed potential

$$E = P \cos pt + Q \cos qt \tag{2}$$

in (1), we get directly

$$\begin{aligned} I = {} & a_0 + a_1(P \cos pt + Q \cos qt) \\ & + a_2(P^2 \cos^2 pt + 2PQ \cos pt \cos qt + Q^2 \cos^2 qt) \\ & + a_3(P^3 \cos^3 pt + 3P^2Q \cos^2 pt \cos q \\ & \quad + 3PQ^2 \cos pt \cos^2 qt + Q^3 \cos^3 qt \\ & + a^4(P^4 \cos^4 pt + 4P^3Q \cos^3 pt \cos qt \\ & \quad + 6P^2Q^2 \cos^2 pt \cos^2 qt + 4PQ^3 \cos pt \cos^3 qt + Q^4 \cos^4 qt) \\ & + \cdots. \end{aligned} \tag{3}$$

In the usual analysis it is customary to expand the powers of the cosine terms in this equation in terms of multiple angles of pt and qt, and of their sums and differences. In the present case we shall depart from this procedure since a slightly different method of handling the equation leads at once to the same numerical result, but has the added advantage of being amenable to a physical interpretation which provides the keynote for the proposed simplification in the study of non-linear devices.

To show this, expand the powers of cos qt, only, in equation (3) in terms of multiple angles and get

$$\begin{aligned} I = {} & \left[a_0 + a_1 P \cos pt + a_2 P^2 \cos^2 pt + a_2 \frac{Q^2}{2} + \frac{3}{2} a_2 PQ^2 \cos pt + \cdots \right] \\ & + \left[a_1 Q + 2a_2 PQ \cos pt + a_3(3P^2Q \cos^2 pt + \frac{3}{4}Q^3) + a_4(4P^3Q \cos^3 pt \right. \\ & \qquad \left. + 3PQ^3 \cos pt) + \cdots \right] \cos qt \\ & + \left[\frac{1}{2} a_2 Q^2 + \frac{3}{2} PQ^2 \cos pt + a_4(3P^2Q^2 \cos^2 pt + \frac{1}{2}Q^4) + \cdots \right] \cos 2qt \end{aligned} \tag{4}$$

$$+\left[\frac{1}{4}a_3Q^3+a_4PQ^3\cos pt+\cdots\right]\cos 3qt.$$
$$+\cdots.$$

Next, this equation may be transformed by the expansion of the powers of cos pt into multiple angles, and the result may be written in the form:

$$\begin{aligned} I=&[b_{00}+b_{01}\cos pt+b_{02}\cos 2pt+b_{03}\cos 3pt+\cdots]\\ &+[b_{10}+b_{11}\cos pt+b_{12}\cos 2pt+b_{13}\cos 3pt+\cdots]\cos qt\\ &+[b_{20}+b_{21}\cos pt+b_{22}\cos 2pt+b_{23}\cos 3pt+\cdots]\cos 2qt\\ &+[b_{30}+b_{31}\cos pt+b_{32}\cos 2pt+b_{33}\cos 3pt+\cdots]\cos 3qt\\ &+\cdots. \end{aligned} \tag{5}$$

The key to the problem is supplied by this equation. It shows that terms of the fundamental q frequency may be thought of as undergoing an amplitude variation produced by a bias variation, $P\cos pt$. To take one example, the average value of the current of the q frequency is given by the average value of the second term of (5), namely, by the coefficient, b_{10} so that

$$I_q=b_{10}\cos qt=\left[a_1+3a_3\left(\frac{P^2}{2}+\frac{Q^2}{4}\right)+\cdots\right]Q\cos qt. \tag{6}$$

The general method for finding the fundamental component when two voltages are applied to the grid of a non-linear device may therefore be stated as follows: By calculation or experiment, find the amplitude of the output current of the q frequency when it alone is applied to the grid of the tube and plot the result as a function of the biasing voltage. Now imagine that the biasing voltage is varied at the rate and through the amplitude swing of the other applied voltage, $P\cos pt$. The amplitude of the q frequency current undergoes corresponding variations, and the average of this value gives the average amplitude of the current output of the q frequency.

This is shown graphically in the construction of Fig. 1 for the fundamental current component of one of the two frequencies present in the applied voltage wave. The static current-voltage curve of the non-linear device is represented by (a) from which the relation between fundamental current output and bias is derived and shown by (b). If the superposed voltage component is shown at (c), the fundamental current output will vary according to (d), and the average ordinate corresponding to the desired result, b_{10}, is indicated. In the case as-

sumed for the drawings, it is seen that the superposition of the second voltage results in a reduction of the initial small output component. The progressive reduction with increase of the superposed voltage may also be visualized.

In a similar way the second harmonic current from one of the applied voltages may be calculated. From (5) the third term gives the amplitude of the second harmonic of the q frequency as it is varied through the p cycle. The average value of this amplitude, namely b_{20}, is the average amplitude of the $2q$ frequency current. The graphical application of this is shown in Fig. 1 in which (e) represents the variation of $2q$ with bias, and (f) represents the resultant output as

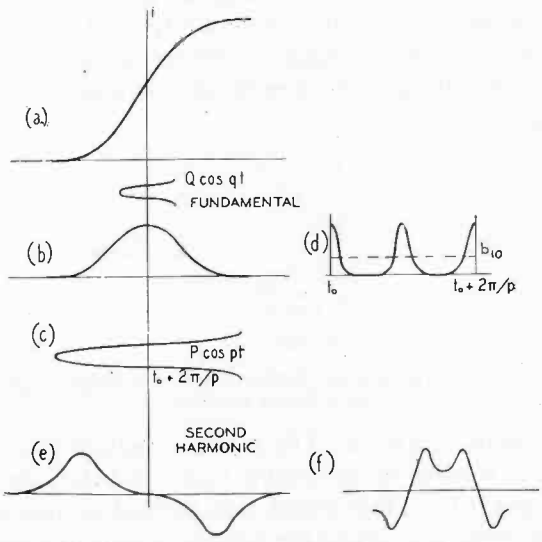

Fig. 1—Construction for derivation of current components from static characteristic.

affected by the superimposed wave which results in an increase over that initially present.

For the higher harmonics the procedure is in every case exactly similar.

Of particular importance to radio engineers is the calculation of the side bands which are produced by the beating together of the two frequencies applied to the input. These may be found and the method of finding them may be given a simple physical interpretation by reference again to (5). For instance, the second order side band $(p\text{-}q)$ results from the second term of (5) when the amplitude of the q frequency undergoes a variation at the rate p. The amount of this

variation is given by the coefficient, b_{11}. Each side band has an amplitude equal to $b_{11}/2$ since $\cos pt \cos qt = \frac{1}{2}[\cos(p+q)t + \cos(p-q)t]$. In the graphical solution, we plot the amplitude of one fundamental, (q), over a cycle of the other fundamental, (p), and analyze the resultant wave form for the component of the p frequency. One half this component then represents the side-band amplitude. A special case will illustrate the method somewhat more clearly.

Consider the linear rectifier in which one of the fundamentals, P, is much greater in amplitude than the other, Q. The applied wave shape and the static current voltage characteristic for the rectifier are shown in Fig. 2. The amplitude of the q current component is equal to αQ, independent of P so long as the entire variation of the q frequency is positive, and it is zero during the time when the variation of the q frequency is negative. Hence when P is much greater than Q, the q amplitude over a cycle of p is represented by the dia-

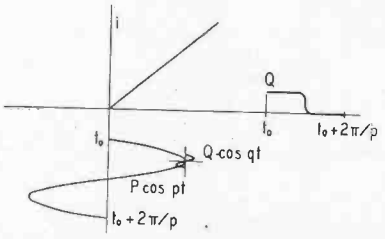

Fig. 2—Construction for derivation of side-band amplitude in a linear rectifier.

gram at the right of Fig. 2. The p component of this wave is well-known to be $2/\pi$ times the maximum value, and the side-band current is half this quantity. This result was arrived at previously on the basis of a laborious and direct analysis by means of Bessel Functions which has received excellent experimental confirmation.[1]

Application to a Heterodyne Detector

The following treatment has for its object the formulation of simple mathematical expressions which apply in the case of a heterodyne detector where the beating oscillator voltage applied to the vacuum tube is not small. This detector is usually placed at the beginning of an intermediate-frequency amplifier for the purpose of transforming the frequency of a weak high-frequency incoming signal to an intermediate frequency of such value that amplification may readily be accomplished. On the grid of the heterodyne detector, therefore,

[1] Peterson and Keith, "Grid current modulation," *Bell Sys. Tech. Jour.*, 7, p. 138.

the small voltage induced by the radio signal is applied together with a large locally generated beating oscillator voltage which differs in frequency from that of the radio signal by the amount of the intermediate frequency of the amplifier.

The particular problem of the heterodyne detector is more easily treated by a method which is in a sense inverse to that discussed in connection with Fig. 2. In the heterodyne detector case the radio signal is very much weaker than the locally generated signal. At the same time the locally generated signal is usually known in amplitude to a much greater precision than is the incoming radio signal. Therefore, for calculation it is best to compute the amplitude of the fundamental component of the locally generated frequency as a function

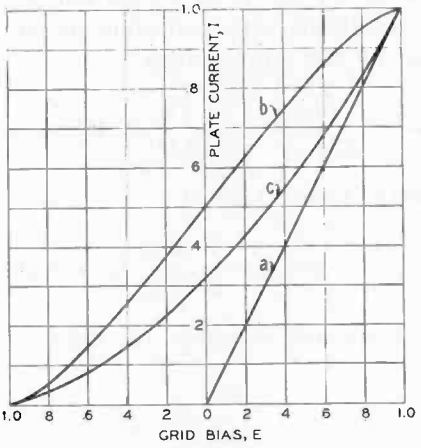

Fig. 3—Direct-current and fundamental current components as a function of grid bias for linear rectifier.

of bias and then to find out how this amplitude varies as the bias is changed by the incoming radio signal. The general graphical method is applicable to any shape of static characteristic. However, for illustrative purposes and for a quantitative conception of the kind of result to be expected from heterodyne detectors, it is instructive to consider several special cases in which simple forms of the static characteristic are assumed.

For the simplest case the static characteristic is assumed to be linear as shown at (a) in Fig. 3, where $I = KE$ for positive values of E, and $I = o$ for negative values of E. This figure expresses the relation between grid bias and space current. Now suppose a local carrier, $P \cos pt$, to be applied. The output current of the p frequency as a

function of the bias may be computed by well-known methods. The result is

$$I_p = \frac{PK}{\pi}\left[\alpha - \frac{1}{2}\sin 2\alpha\right]\cos pt \tag{7}$$

where α is half the angle during which current flows per cycle. The bias, M, may be expressed in terms of α by the relation

$$M = -P\cos\alpha.$$

The form of (7) is shown at (b) in Fig. 3. We now wish to find out how the amplitude of this component changes with bias when the bias varies according to the form, $Q\cos qt$. To do this consider the amplitude of I_p as given by (7) as a function of the bias, M. The variations of the amplitude with variations of the bias may then be formally expressed by the power series

$$\Delta I_p = \frac{\partial I_p}{\partial M}\Delta M + \frac{1}{2}\frac{\partial^2 I_p}{\partial M^2}(\Delta M)^2 + \cdots$$

and when ΔM has the form, $Q\cos qt$,

$$\Delta I_p = \frac{\partial I_p}{\partial M}Q\cos qt + \frac{1}{2}\frac{\partial^2 I_p}{\partial M^2}Q^2\cos^2 qt + \cdots$$

the fundamental component of which, for small values of Q, has the amplitude

$$\frac{\partial I_p}{\partial M}Q$$

which is seen to be proportional to the slope of the curve of (7) as plotted as a function of the bias, M, on Fig. 3. From (7) this is equal to

$$\frac{2KQ}{\pi}\sin\alpha. \tag{8}$$

The side-band amplitude of p-q frequency has been shown to be one-half this value, so that we have

$$I_{p-q} = \left[\frac{KQ}{\pi}\sin\alpha\right]\cos(p-q)t. \tag{9}$$

Thus far our application has included only those cases in which the impedance external to the non-linear device is zero. In practice this is rarely so. Fortunately, however, in the special case of the heter-

odyne detector just discussed, the impedance in the external circuit is usually finite for the side-band frequency and zero or very small for all other frequencies. Therefore, in the analysis just given, (9) may be interpreted as the short-circuit current from a generator of internal resistance, r, and generated voltage Ir. The value of r is the internal plate impedance of the vacuum tube. If this value can be found for cases like the present, where operation takes place partly below cut-off, then the resulting voltage across an impedance, Z, is given by the well-known expression,

$$E_{p-q} = I_{p-q} \frac{rZ}{r+Z}. \tag{10}$$

In order to determine the internal impedance of the vacuum tube when it is subjected to a large impressed voltage on the grid side, it is necessary to review briefly the fundamental attributes of the resistance sought. We think of the tube as being in operation with the large voltage $P \cos pt$ applied to the grid and wish to find the resistance which the tube offers to a small current of p-q frequency flowing in the plate circuit.

The space current may, as usual, be represented by writing the functional relation

$$I_p = I_p(E_p, E_g)$$

where, in this case, E_g consists of the bias, M, and the steady wave, $P \cos pt$ from the beating oscillator. Consider the effect of varying the plate potential while these voltages are applied to the grid. Under such conditions the change in I_p produced by a small change in E_p may be expressed by the Taylor's series expansion

$$\delta I_p = \frac{\partial I_p}{\partial E_p} \delta E_p + \frac{1}{2} \frac{\partial^2 I_p}{\partial E_p^2} \delta E_p^2 + \cdots.$$

For very small changes in E_p the first term, only, of this series may be used. Then, since for a constant value of E_p the plate current resulting from the bias M and the voltage, $P \cos pt$ on the grid may be written in the form

$$I_p = a_0 + a_1 \cos pt + a_2 \cos 2\,pt + \cdots$$

the first term of the Taylor's series expansion gives

$$\delta I_p = \frac{\partial I_p}{\partial E_p} \delta E_p = \frac{\partial a_0}{\partial E_p} \delta E_p + \frac{\partial a_1}{\partial E_p} \cos pt\, \delta E_p + \frac{\partial a_2}{\partial E_p} \cos 2\,pt\, \delta E_p + \cdots.$$

If δE_p is of the form, $S \cos st$, where s may ultimately be put equal to $(p-q)$, we may write the component of δI which has the s frequency as follows for the case where $s \neq hp$, so that harmonic relations are excluded:

$$I_s = \frac{\partial a_0}{\partial E_p} S \cos st.$$

But the voltage which produced this current was $S \cos st$. Hence, the plate resistance to the s frequency is

$$r = \frac{E_s}{I_s} = \frac{S \cos st}{\frac{\partial a_0}{\partial E_p} S \cos st} = \frac{1}{\frac{\partial a_0}{\partial E_p}}.$$

Such a resistance is the one sought for the heterodyne problem, since s may be taken equal to $(p-q)$. The resistance, r, is thus seen to be given by the reciprocal of the slope of the curve which shows the d-c space current as a function of plate potential while the tube is in operation with the beating oscillator applied to the grid.

In the special case of the linear characteristic which was discussed above, this slope is easily found by calculation under the restriction that the tube employed satisfies Van der Bijl's relation that the space current is a function of $(E_p/\mu + E_g)$, for then the rate of change of the d-c space current with plate potential is just μ times the rate of change of d-c space current with grid potential. As a function of grid potential we may write the d-c space current as follows:

$$I_0 = \frac{PK}{\pi}\left[\sin \alpha - \alpha \cos \alpha\right] \tag{11}$$

as shown at (c) in Fig. 3. The slope of this curve is given by

$$\frac{\partial I_0}{\partial E_g} = \frac{\partial I_0}{\partial M} = \frac{K\alpha}{\pi}$$

which, under Van der Bijl's relation is proportional to $1/r$. Hence

$$\frac{1}{r} = \frac{K\alpha}{\mu\pi}. \tag{12}$$

Therefore, having the value of the internal plate impedance of the tube, as given by (12), we may write from (9), (10), and (12), the voltage across the impedance Z which occurs from the side band produced

by the incoming radio signal beating with the locally generated carrier. This voltage is

$$E_{p-q}=\left[\frac{KQZ}{\pi}\,\frac{\sin\alpha}{1+\dfrac{KZ\alpha}{\mu\pi}}\right]\cos\,(p-q)t. \tag{13}$$

From this special application of the method to the case of a tube with the linear characteristic of Fig. 3, the application to the general case where the equation of the static characteristic is not known may easily be inferred. It is necessary to know the way in which the d-c space current varies as a function of the plate potential while the local oscillator is in operation, and it is necessary to know the manner in which the fundamental component current resulting from the local oscillator varies as a function of grid bias. With the knowledge of these two things, the equations

$$E_{p-q}=I_{p-q}\left\{\frac{rZ}{r+Z}\right\}\;;\;\; I_{p-q}=\frac{1}{2}Q\frac{\partial}{\partial E_g}\left|I_p\right|\;;\;\; \frac{1}{r}=\frac{\partial I_0}{\partial E_p}$$

may be applied directly to give the side-band voltage amplitude across the impedance when the incoming radio signal is applied.

For reference the analytical expressions which arise when the static characteristic satisfies the square-law relation, instead of being linear as was heretofore assumed, may be written as follows:

$$E_{p-q}=\frac{\dfrac{KPQZ}{\pi}\left[\alpha\sin\alpha+\dfrac{1}{4}\cos 3\alpha-\dfrac{1}{4}\cos\alpha\right]}{\sin\alpha+\dfrac{KPZ}{\mu\pi}\left[2\sin^2\alpha-\alpha\sin 2\alpha\right]}\cos\,(p-q)t \tag{14}$$

which applies when the local voltage, $P\cos pt$, carries the operation below cut-off, and

$$E_{p-q}=\left[\frac{KPQZ}{1+\dfrac{2KZN}{\mu}}\right]\cos\,(p-q)t \tag{15}$$

where N is the bias voltage above the cut-off point, which applies when operation is always above the cut-off point.

In the special case of the heterodyne detector physical conditions are such that the external impedance is zero to both the frequencies of the applied voltage. The circumstance that one of the applied volt-

ages is very much smaller than the other enables the effect of the external impedance to the beat frequency to be introduced without disturbing the relations for the fundamentals.

The validity of the results obtained has been demonstrated for the case in which only potentials of fundamental frequency were impressed on the non-linear element. This state of affairs does not always exist. Where there is an external impedance to the new frequencies produced by wave-form distortion, the potential impressed on the non-linear element is modified by the voltage-drop of the distortion currents through the external impedance. Of course this effect becomes of importance only where the distortion potentials become comparable in magnitude with the fundamentals. In that event the fundamental amplitudes are altered for two distinct reasons. First, the distortion potentials cause a different region of the characteristic to be traversed than is the case in their absence—a loading effect. Then, too, the energy dissipated and stored by the distortion products is taken from the fundamental sources simply on the basis of energy conservation, a phenomenon sometimes described as the reaction effect. These two effects[2] then are operative in the case of badly distorted waves, over and above the relations which we have treated analytically above. They may be included by the familiar device of successive approximations.

The application to the heterodyne detector which was dealt with here in some detail may be extended to several other specific cases of a similar character. In practice it provides a simple and convenient means of arriving at both qualitative and quantitative results in detectors and modulators of many kinds where the input voltages are so large that the usual power series formulation requires a prohibitively large number of terms. The two important points in the application of the method to the heterodyne detector may be summed up in the following statements:

1. The side-band short-circuit current is proportional to the slope of the curve which shows the fundamental component of the output current resulting from the beating oscillator as a function of the grid bias.

2. The internal impedance of the detector is equal to the reciprocal of the slope of the curve which shows the d-c component of the output current resulting from the beating oscillator as a function of plate potential.

[2] Described at length in *Trans. A.I.E.E.*, XLVI, p. 528.

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PLATE-VOLTAGE SUPPLY FOR NAVAL VACUUM-TUBE TRANSMITTERS

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Summary—*This article outlines the Navy's experience and conclusions in regard to the various types of plate supply, for vacuum-tube transmitters, which have been used. After listing and briefly discussing the considerations governing the selection of an ideal plate supply for transmitters, a comparison is made between the various types and the ideal. Navy experience in regard to character and control of output, source of primary power, reliability and repairs, ruggedness and efficiency is discussed in some detail. Data regarding comparative first costs and operating costs are given, followed by a statement of the Navy's present policy in regard to plate supply. In conclusion, the advantages and disadvantages of the motor generator and the mercury-vapor rectifier tube are tabulated.*

Introduction

BY the end of the World War, Service opinion in the Navy had become practically crystallized in the belief that the days of the arc and spark transmitter were numbered, and that they would be supplanted by vacuum-tube transmitters in all except possibly the larger shore installations where the arc and the radio-frequency alternator still had certain advantages not at that time enjoyed by tubes. At that early date, opinion was still divided as to the necessity, and even the desirability, of having a pure CW output for all transmitters. The rapid development of radio and the unparalleled expansion of its use for communications and broadcasting forced the conclusion, in a relatively short time, that nothing but practically pure CW output could be tolerated in the not too distant future, either for ships, operating in close proximity in large fleets, or for shore stations.

The decision was therefore made at that time to purchase no more spark or arc equipment, but to bend every effort to ward the development of tube transmitters and to encourage the commercial production of types of tubes and of tube transmitters, suitable for all Naval uses. The object in view was to replace all obsolescent equipment with vacuum-tube apparatus as rapidly as the progress of development warranted and available funds permitted. In the train of this

* Dewey decimal classification: R344. Presented at New York meeting of the Institute, September 4, 1929, by Lieutenant-Commander R. C. Starkey.

decision there followed closely the problem of the development of a suitable source of direct current for the plate-power supply, consisting of a supply of relatively low voltage, the required value of which, however, has been constantly increasing until the present time, when we mention 18,000 volts direct current quite calmly.

Owing, however, to the great quantity of older types of power equipment in existence in the Service and, in some degree, to the early lack of certainty in regard to the necessity for going at once to pure CW, a transitional stage was passed through; a stage in which ACW (self-rectified a-c plate supply) was used to advantage. The power supply already available for the almost universally used spark transmitter (500-cycle alternating current at 220 volts) was too tempting and too economical to overlook. As a result, a number of full-wave self-rectifying transmitters were developed, using a 500-cycle supply with the modified spark set transformers or more suitable units, and introduced into the Service. These filled the gap until the transmitters of today could be developed to their present reliable stage and be produced and obtained in sufficient quantity to meet our requirements.

Considerations Governing the Selection of an Ideal Plate Supply

In considering the ideal plate supply for Naval transmitters, one is at first struck, and in most cases somewhat appalled, by the extent and ramifications of the problem. One must consider the battleship, and large cruiser, each with its battery of several transmitters, the destroyer leader and destroyer, the submarine and the aircraft, in connection with the mobile services; and the great variety of shore station transmitters, ranging in size from the largest transoceanic stations to the smallest coastal radiocompass stations and in locations from the Tropics almost to the Arctic circle, under extreme climatic conditions, in connection with the fixed services.

Naturally, in order to approach such a problem with hope of obtaining the best practical solution, it is necessary to consider the broad range of requirements, and perhaps to accept separate solutions in order to meet the several requirements.

In order to analyze the problem, we may find it useful to list, as nearly as practicable in their order of importance, the characteristics which the ideal plate supply for Naval transmitters should possess. In this way we find certain characteristics which should be common to all, and certain others which are essential to some and perhaps not necessary or even desirable in other types of installations.

Character of Output. A constant d-c power output, sufficient to supply the specific plate-potential and plate-current requirements of the transmitter and free from objectionable ripple and voltage variation, is naturally a primary requirement.

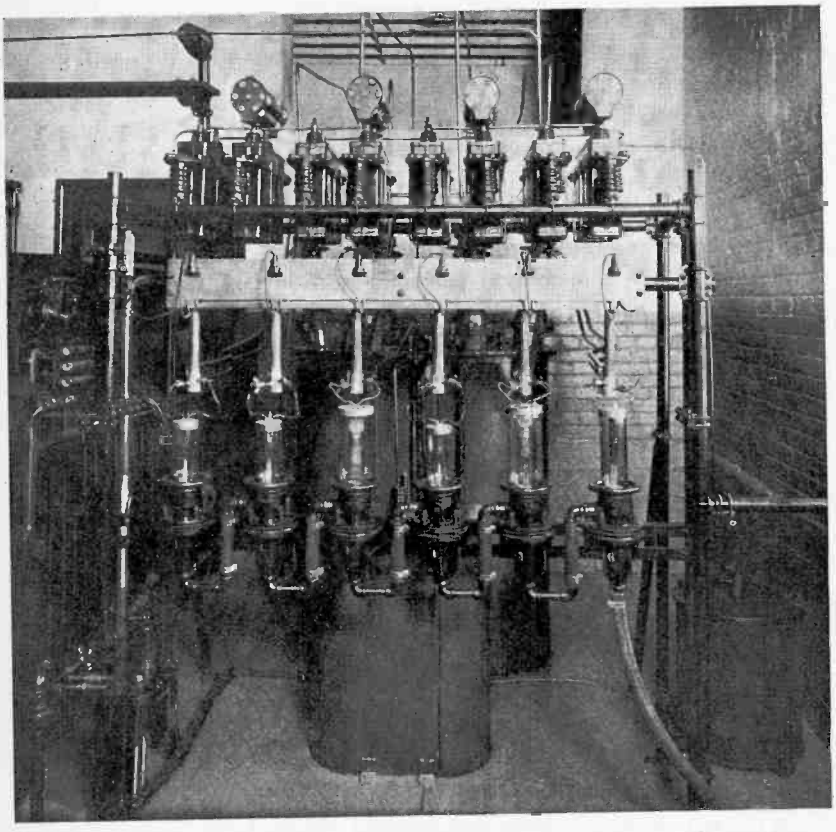

Fig. 1—Front view (fence removed) rectifier tube rack. Type CG 2938 tubes. U. S. Naval Radio Station.

Smooth variation of voltage over a reasonably wide range with good regulation is essential to provide satisfactory control of transmitter output.

Available Primary Source of Power. The apparatus, of whatever nature, must be capable of operation from the available source of power. On shipboard the source is almost invariably 115 or 230 volts direct current. On shore the source may be similar but is more often commercial, alternating current differing in voltage, frequency, and number of phases.

Overload and Protection. The device must be capable of withstanding certain overloads, such as may occur in operation of tube transmitters, within the limits of its protective devices, and it must be safeguarded beyond such limits by suitable positive acting auxiliary devices.

Reliability and Repair. Interruptions to service, due to failure of parts, must be kept to a minimum and, when they do occur, rapid replacement or repair must be provided for. The apparatus must be capable of reliable operation, and such ordinary repair and maintenance as it requires, by average Service personnel, including relatively inexperienced men in time of war.

Moisture Proof. All such apparatus must be moisture proof to a degree. The degree depends upon the use to which it is placed and varies widely in the Naval Service from actual submergence to protection against moist salt air.

Ruggedness. The apparatus must be of sufficiently rugged parts and construction to withstand the shocks incident to shipping and handling, and in most cases those shocks incident to heavy weather at sea and gunfire.

Cost. The total cost considering the first cost, the cost of operation, of upkeep, of replacements and repairs, must not be excessive.

Space and Weight. The importance assigned to these requirements is necessarily variable. It is of vital importance in aircraft and small ships, of somewhat less importance in large ships, and of small consideration at most shore stations.

Efficiency. The efficiency must be as high as is consistent with the other requirements.

The Characteristics of the Available Types—How Closely They Approximate the Ideal

In Naval practice, as in commercial, there have been generally used but two methods of obtaining direct current for plate supply for transmitters of more than a few watts power. They are, of course, the high-voltage direct-current generator, with its motive power, which is usually an electric motor, and the vacuum-tube rectifier with its associated transformers and filter system. The tube rectifiers are of two general types, the older thermionic rectifier tube and the newer hot-cathode mercury-vapor rectifier tube. The Navy has had some experience in the use of all three. Its use of motor generators has been very extensive, its use of thermionic tubes only less so, and lately some experience has been had with the mercury-vapor type. It may, therefore, be of interest to discuss the characteristics of

each type as demonstrated in Service use as compared with the ideal requirements outlined in a previous paragraph.

Motor Generators. At present there is no difficulty in purchasing commercially good d-c generators of any voltage up to 12,000 v. If driven by a d-c motor, with fairly constant supply, the voltage

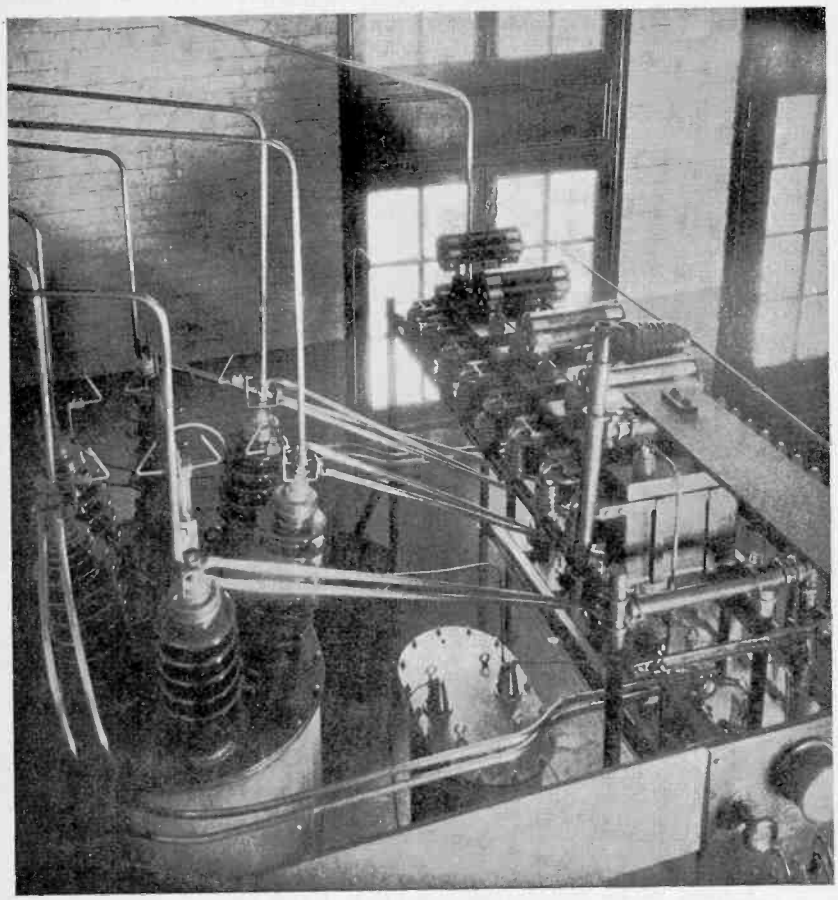

Fig. 2—Top view, filament transformer and rectifier tube rack. 80-kw tube transmitter. U. S. Naval Radio Station.

variation is well within the required limits. The regulation can, by variation of the compounding, be made to meet the requirements. It is usual, I believe, so to design the generator that at normal full output voltage the change in voltage is approximately 5 per cent when the load is thrown off. By compounding, to provide the required maximum regulation at this point, the regulation at the various other

points is held within reasonable limits. It is possible to obtain a continuously variable change of voltage from a point slightly above one-half normal voltage up to 25 per cent over voltage. This smooth variation over such a wide range is a very desirable characteristic for Naval transmitters. In this connection, however, there is one point that should be noted. A generator may have such regulation at normal voltages that when the full load is thrown on the voltage will fall slightly

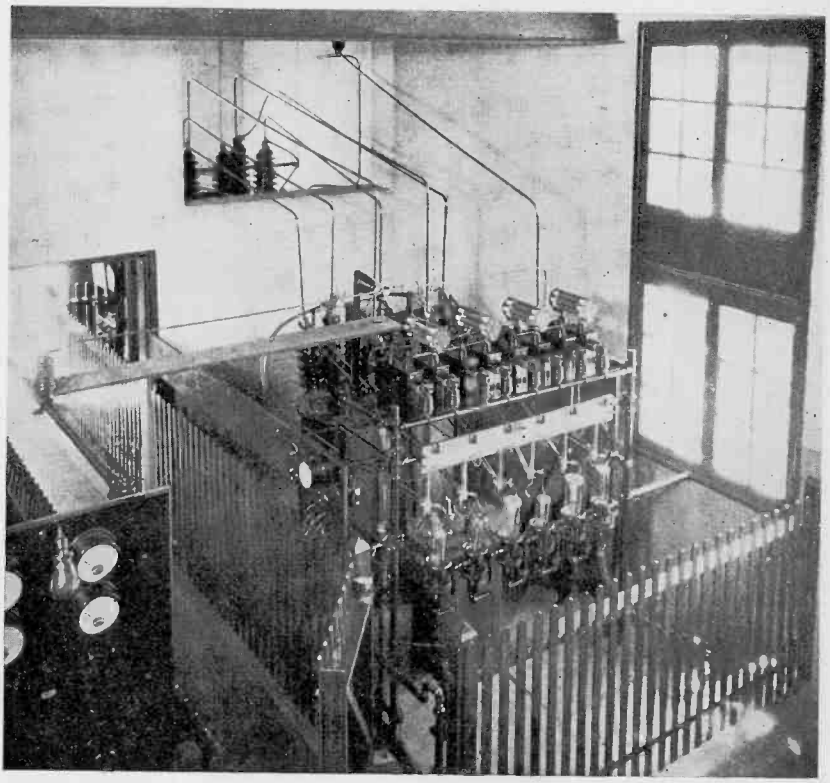

Fig. 3—Filament transformer and rectifier bank, showing leads to plate transformer. 80-kw tube transmitter. U. S. Naval Radio Station.

(positive regulation), but at about one-half normal voltage, any increase in load current may cause an appreciable and undesirable increase in voltage (negative regulation), resulting in an unstable condition which, combined with an unstable condition in a radio transmitter, may cause serious trouble. This may result from the design when attempt is made to provide for too wide a voltage range, or from the use of full load flat compounded generator at low voltage with full

load current values. The series field is designed for a definite amount of compounding at normal full load current and voltage, and the terminal voltage is controlled by adjustment of the separately excited shunt field. When the shunt field is weakened to obtain lower terminal voltages, the series field strength remains approximately the same, due to the fact that the transmitter has been adjusted for full load current of generator. Under these conditions, the effect of the series field predominates, and excessive compounding results. It has been found desirable, therefore, in certain installations where generators were required to operate temporarily at considerably reduced voltage but approximately full load current, to provide a variable degree of compounding by use of a suitable variable resistor or rheostat shunting the series field, which is usually connected in the negative side of the circuit at ground potential.

Tube Rectifiers. The thermionic vacuum-tube rectifiers employed in the past had a number of very serious limitations. They had very poor regulation on account of the large potential drop in the tubes, which necessarily involved large tube losses, low efficiency and consequent necessity of providing for dissipation of much heat. This requires generous spacing in design of the tubes and construction of the rectifier, resulting in a bulky rectifier unsuitable for shipboard use. For these reasons they were practically never used aboard Navy ships, and their use at shore stations was somewhat limited.

The advent of the hot-cathode mercury-vapor tube has greatly changed the aspect of the situation. This type possesses the very desirable feature of low potential drop or small space charge. As a result of this, it has good regulation. The actual drop in the tubes in a single-phase simple rectifier is approximately 15 volts. Due to the lower losses, the new tubes are smaller in size, resulting in a considerable reduction in dimensions of the complete rectifier equipment. Whatever regulation is involved in the rectifier, over all, is due almost entirely to transformer and line drop. For this reason, very positive protective apparatus is required; otherwise, with such good regulation, a short circuit may be disastrous. The rectifier should be designed to have a definite value of regulation, thus having inherent protection. With a regulation of approximately 8 per cent in a standard 100-kw 20,000-volt rectifier (6 tubes) it is possible to obtain a fair degree of inherent protection. A somewhat serious difficulty with rectifiers in general is that it is difficult to obtain a smooth variation of output voltages particularly when combined with good regulation. It is generally necessary, and best, to select some five different output voltages to suit the tuning and general operating requirements of the

transmitters and limit the obtainable variations to these. But in the matter of regulation there is a point in favor of the rectifier—it has positive regulation at any voltage tap—that is, a fall in voltage when the load is applied, instead of a rise, as in some cases might happen with a generator operating at low voltages.

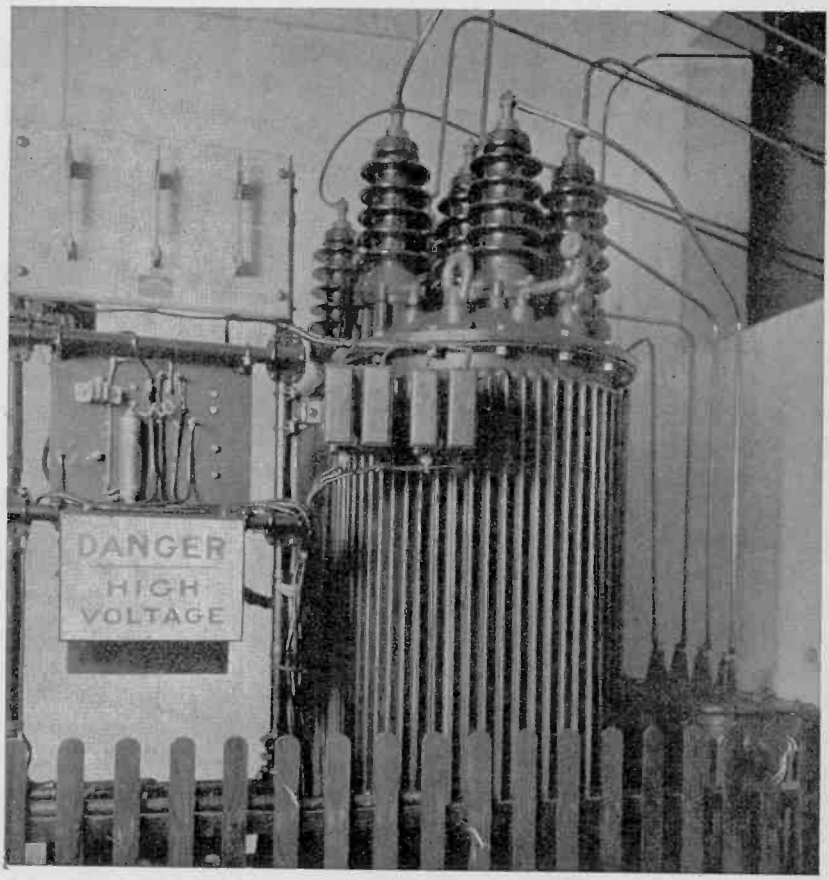

Fig. 4—Plate transformer (side view). 80-kw tube transmitter. U. S. Naval Radio Station.

The rectifier generally requires a fairly good filter system which occupies a good deal of space, and is a factor which must be considered in connection with the space occupied by the two systems. The motor generator will also usually require a filter, but it can generally be made small. The larger filter may be considered as a disadvantage of the rectifier.

Available Primary Source of Power. The high-voltage, d-c generator can be turned over by almost any available source of power. On board ship the driving motor is almost universally a direct-current motor, as that is the type of power available aboard practically every

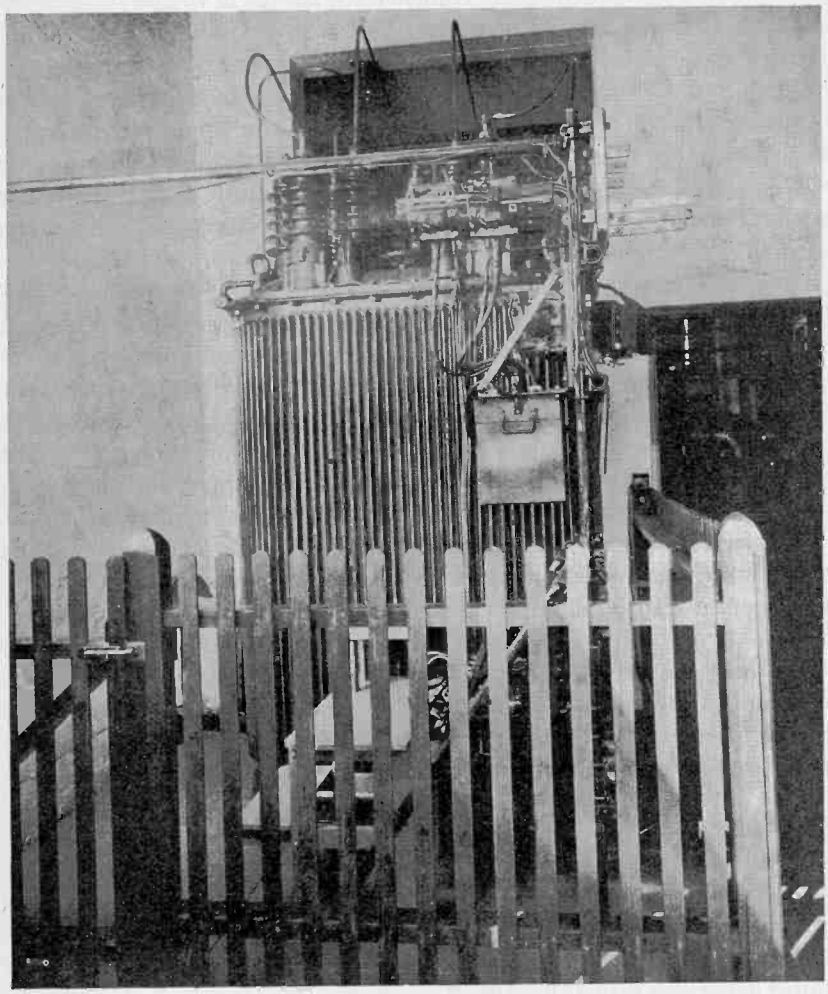

Fig. 5—Plate transformer. West side view of the disconnect switch panel. 80-kw tube transmitter. U. S. Naval Radio Station.

Naval ship. This gives great flexibility and at the same time permits a high degree of standardization and interchangeability. Such interchangeability has been found highly necessary during the complete change from the old to the new type of transmitters and associated

apparatus, which the rapid advance in the radio art has entailed. For reasons of economy, the change-over could not be made wholesale nor all in one year, and removal of transmitters from one type of ship and re-installation on another was necessary as newer and better transmitters were developed. Another advantage of the motor generator is that, as d-c motive power can be made available in almost any part of a ship, the motor generator can be placed wherever space is available and convenience makes desirable, although it is of course desirable to keep the high-voltage leads from the generator short, for it is essential to protect the personnel and avoid risk of explosion. For these reasons, it has been the usual practice to supply each transmitter with its own d-c motor-driven d-c generator for shipboard use, and to supply generators for shore stations driven by motors suitable for the power available at each.

The proposition of having a combined central source of power aboard ship with individual rectifiers for all transmitters and perhaps for receivers also, looks very attractive, particularly for large ships, now that a suitable tube rectifier is available. On the other hand, a suitable a-c power supply is required in order to use rectifiers, and such a supply is not generally available on Navy ships. It may, however, be feasible to provide for a three-phase, 60-cycle, 220-volt supply as a universal source for all radio transmitters. In addition, this supply could be used to operate the receivers, although only a single phase would be necessary. The generator for such a system could be of standard commercial type, preferably turbo-driven and might be expected to give very little trouble owing to its low voltage and rugged characteristics. It would be essential to provide two such generators in different parts of the ship, to provide against failure, particularly in action. With such a system, the rectifiers for each transmitter could doubtless be built into the transmitter itself. Using the new tubes, they would not occupy much space. High-voltage leads would be reduced to a minimum and the use of a large number of high-voltage motor generators would be abolished.

Reliability and Repairs. The most vulnerable part of a motor generator is its high-voltage armature. If this is injured, the machine and its associated transmitter is out of commission (unless a duplicate motor generator is installed) until a new armature is installed or the old one repaired. To safeguard continuity of operation, a spare armature must be carried. Care must be taken to see that the spare is kept free from moisture in storage, and caution must be exercised when starting to use it, or trouble is imminent. In operation motor generators must be well protected against spray, moisture, oil, the drip from condensed steam, etc., or the insulation of high voltages will give trouble.

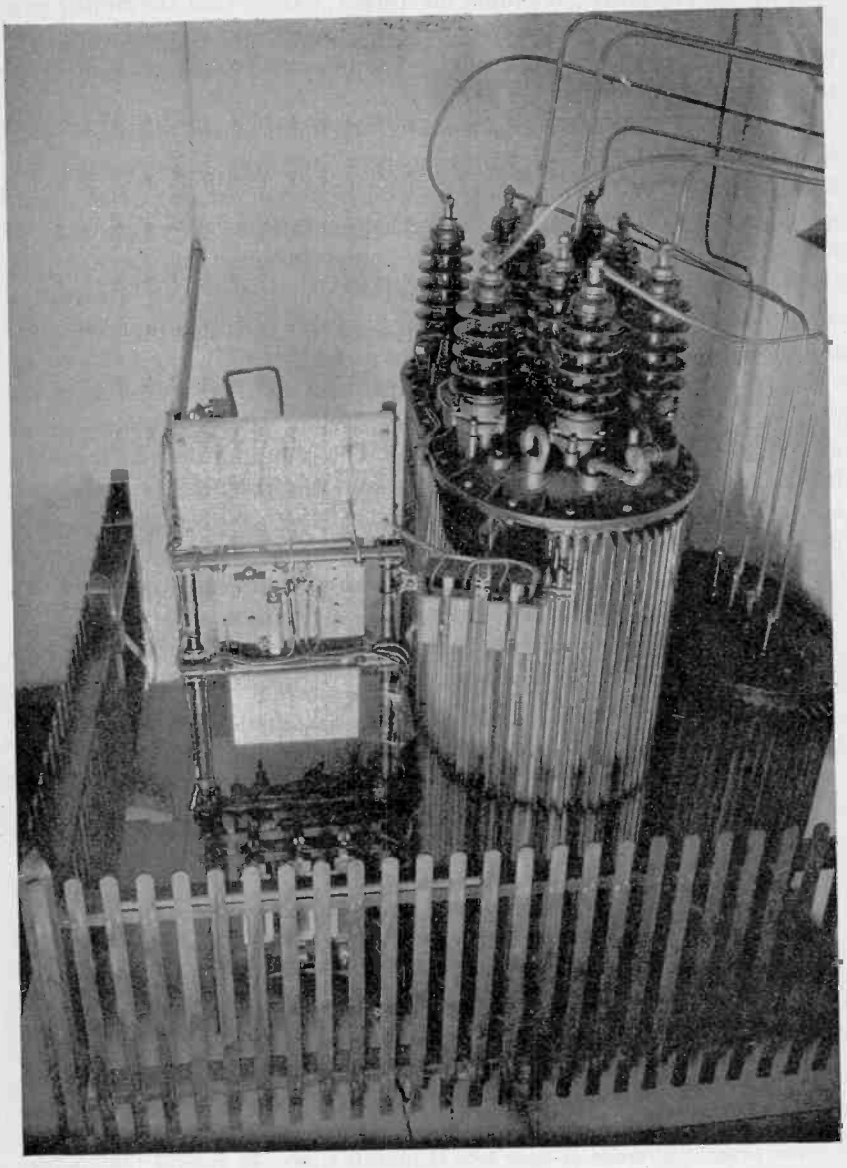

Fig. 6—Disconnect switch panel, plate transformer, and interphase transformer. 80-kw tube transmitter. U. S. Naval Radio Station.

This is not always easy to provide for, especially in small ships, submarines and aircraft. We must not forget, either, that the motor generator is a rotating machine with bearings that require oil and attention, but the self-aligning ball bearing has reduced the trouble in this respect to small proportions.

In the rectifier, generally speaking, the main source of failure is the burning out of the tubes. In this respect, however, improvement has been excellent, and reliable tubes with life well in excess of 1000 hours are commercially available. Nevertheless, failures do occur more or less regularly and although, with a properly designed rectifier unit, the tube can be replaced very quickly, still the service has been interrupted and such interruption, no matter how brief, may be a vital matter during a Naval engagement. Considering a rectifier with from two to six tubes, with an average life of 1500 hours, one can rather definitely count on two to six shutdowns during that period. Failures from motor generators are not nearly so common. The remainder of the rectifier, its transformers, condensers, reactors, and resistors, can be built with a fairly large factor of safety. In the case of a ship operating for long periods far from its base, the number of spare tubes which must be carried and the space occupied for their storage, is a consideration much more serious than the stowage of a spare motor generator.

It may be of interest to quote briefly from a recent report received from a high-powered Navy station:

> "In the twenty-one months since the installation of the 40-kw tube transmitter rectifier, only one failure has occurred. This was due to the burning out of one of the resistance units in the grounding circuit of the rectifier. . . . . In the first 17 months of operation, only one tube failure occurred. The tube had given 4000 hours of operation so no cause of complaint in that case. The cost of replacement was $275.00. Since the installation of the 22-volt filament tube type CG 2938, approximately eight months ago, there has been no failure. They have an average operating time of 2595.27 hours and there is no reason to believe they will not go over 5000 hours. . . . . Another transmitter, on the other hand, uses a motor generator; the motor-generator plate supply has never failed since its installation twenty-one months ago."

From another high-powered station comes the following:

> "Since the installation of the unit (some four years) there has been no transformer trouble and the tube life has continually increased until the present average of over two thousand hours. In case of tube failure a new tube can be installed in a maximum time of five minutes. . . . . In the maintenance of the unit it is necessary to filter the transformer oil every six months and to overhaul the water interlocks every 90 days. Since using softened water trouble with interlocks previously experienced has been practically eliminated."

Ruggedness. In the matter of ruggedness or ability to withstand transhipment, the shocks of gunfire and of heavy weather, the motor generator seems at present to possess advantages not enjoyed by the tube, but the tube is constantly improving in that respect and will probably equal the motor generator in a reasonably short time.

Efficiency. The nature of the source of power affects the overall efficiency of the two types of plate supply. Given a-c power to start with, the efficiency of the hot-cathode mercury rectifier is certainly

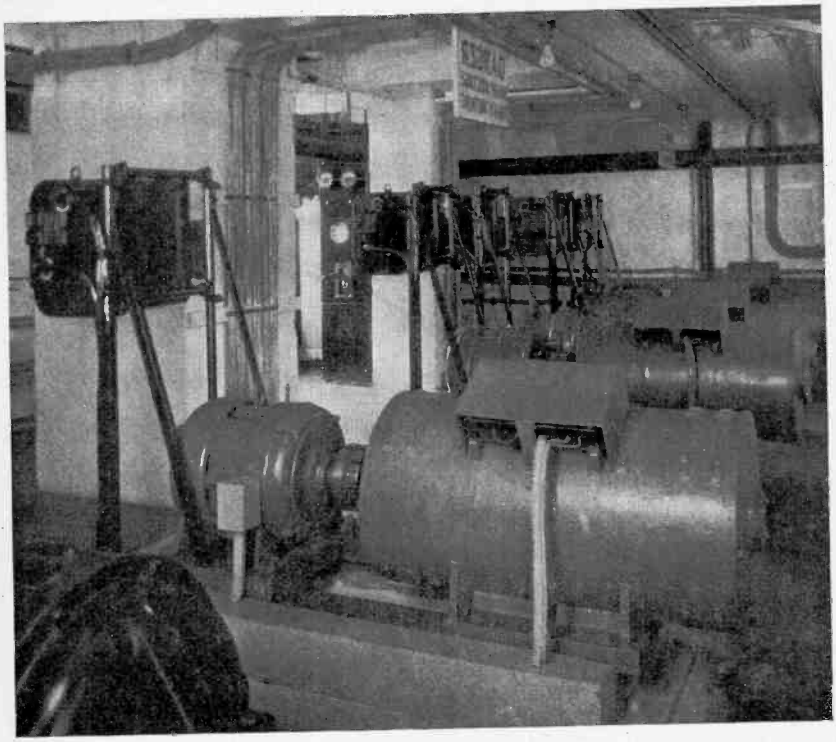

Fig. 7—Five 20-kw d-c generators, 10,000 volts. U. S. Naval Radio Station.

higher than that of a high-voltage generator. The rectifier system may have an efficiency as high as 94 per cent; the motor generator will hardly exceed 70 per cent; but, as has been stated, the primary source of electric power aboard ship is ordinarily direct current, and the motor of the motor generator can operate directly from this source. The rectifier, on the other hand, requires alternating current, which must be generated by a separate motor generator, stepped up and then rectified. However, the efficiency of such a motor generator operating

on direct current and delivering 3-phase alternating current at 220 volts is comparatively high—some 90 per cent; therefore the overall efficiency of such an arrangement would probably exceed the high-voltage d-c motor generator. If a separate turbo generator were used aboard ship to supply the alternating current, much better overall efficiency would of course result.

Some Data Regarding First Cost and Operating Costs. Both the first cost and the operating costs are dependent primarily upon the source of power, so a direct comparison is difficult to arrive at without first evaluating the various factors which enter into the matter. The cost of power, the efficiency of the equipment, its life, the cost and

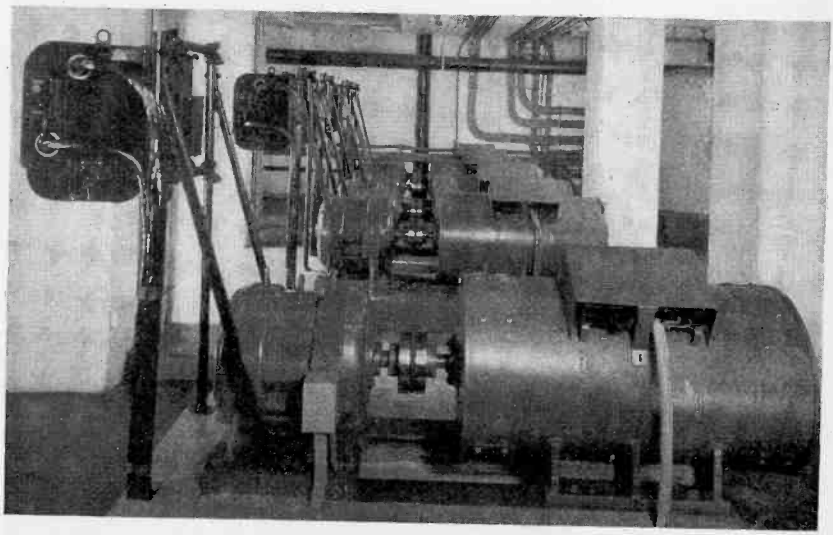

Fig. 8—Five 20-kw d-c generators, 10,000 volts. U. S. Naval Radio Station.

frequency of replacements, cost of repairs, must all be given consideration. The power for Naval shore radio transmitters is usually obtained commercially, and the cost varies with their locations from about 1 to 3 cents per kwh. On ships the cost of power varies with the type of ship, but is usually somewhat less than for shore stations of corresponding power. The cost of tube replacements can be figured fairly accurately, but this is not the case in regard to armature replacements, field coils, etc. If the installation is on shipboard where alternating current is not available, that point must be considered, and if an a-c turbo generator is installed for special radio use, the intermittent and light load must be taken account of. On shore, this is usually not a factor. A

comparison between tubes of nearly equal characteristics shows that the mercury-vapor type costs only slightly more than one-third the cost of a thermionic tube of nearly equal rating, and that the cost per tube per kw is in one case $0.85 and the other $2.95. Although not a great deal of life data is available on the mercury-vapor type, the experience to date indicates that it will be at least equal if not greater than the thermionic tube. In the past the latter tube has been purchased on a 1000-hour guarantee basis, but the average life in our experience has been much higher than that. At the Navy's San Diego station the average life is in excess of 2000 hours, and a life as high as 8000 hours has been obtained in extreme cases.

Some available price data on motor generators, turbo generators and rectifiers are given below:

(a)	Motor generator, 1200 volts, 0.5 kw, d-c drive, complete with starter, filter and control equipment	$ 977.00
		1954.00
	Cost per kw	48.5 per cent
	Efficiency (full load)	
(b)	Motor generator,3000 volts, 3.5 kw complete with starter, filter and control equipment	$2590.00
		740.00
	Cost per kw	67.3 per cent
	Efficiency (full load)	
(c)	Motor generator, 7500 volts, 10 kw complete with starter, filter and control equipment	$3760.00
		376.00
	Cost per kw	63 per cent
	Efficiency (full load)	
(d)	Motor generator, 4000 volts, 7.5 kw complete with starter, filter and control equipment	$1900.00
		253.00
	Cost per kw	60 per cent
	Efficiency (full load)	
(e)	Motor generator, 10,000 volts, 20 kw complete with starter, filter, metering and control equipment	$5000.00
		250.00
	Cost per kw	70 per cent
	Efficiency (full load)	
(f)	Rectifier, 20,000 volts, 100 kw complete with starter, filter, metering and control equipment	$11,150.00
		111.50
	Cost per kw	94 per cent
	Efficiency (full load)	
(g)	Motor generator, 100 kw, 220 volts direct current to 220-volt, 60-cycle, 3-phase alternating current, complete with starter and control equipment	$2788.00
		27.88
	Cost per kw	93 per cent
	Efficiency (full load)	
(h)	Turbine generator, 100 kw non-condensing 220-volt, 60-cycle, 3-phase alternating current. Complete with control equipment	$5300.00
		53.00
	Cost per kw	
(i)	Turbine generator, 100 kw condensing 220-volt, 60-cycle, 3-phase alternating current. Complete with control equipment and condenser. Price	$5950.00
		59.50
	Cost per kw	

From the above it will be seen that as far as original cost is concerned, that of the motor generator is higher than that of the rectifier. This is true even though the source is direct current, as on shipboard, and an extra generator to develop the a-c power for the rectifier is used. For example:

High-voltage motor-generator cost at least	$200.00 per kw.
Efficiency possibly	70 per cent
High-voltage rectifier cost	$111.50 per kw
Efficiency	94 per cent
Generator for alternating current—cost	27.88
Efficiency (full load)	0.93 per cent
Total cost rectifier and a-c generator	$139.38 per kw
Resulting efficiency = (94 × 93) / 100 =	87.4 per cent

If the installation is on shore where a suitable a-c supply is available, the difference in original cost is considerably greater than the

above, due to the fact that an a-c generator is not necessary for the rectifier. This gives the rectifier a considerable advantage.

Bearing in mind that, because there are so many variables to consider, all figures must be considered only approximate and the results obtained applied with caution, it may be useful to compare operating costs in three standard cases.

CASE 1

Source ..... Alternating current
Installation ..... ashore
Cost of power ..... 3 cents per kwh
Rating of installation ..... 100 kw

MOTOR GENERATOR

Output of generator ..... 100 kw
Efficiency. (Highest commensurate with reasonable first cost) ..... 70 per cent
Input to motor 100/0.70 = ... 143 kw
Operating cost (power only full load) 143 × 0.03 ..... $4.29 per hour

RECTIFIER

Output of rectifier ..... 100 kw
Efficiency (Full load value given in proposal of October 16, 1928) ..... 94 per cent
Input to rectifier 100/0.94 = ... 106 kw
Operating cost—power 106 × 0.03 ..... $3.18 per hour
Operating cost of tubes:
Cost per set = 6 × $84.50 = ... $507.00
Cost per hour (1000 hrs. life) = $507.00/1000 = ... $0.51 per hour
Total operating cost ..... $3.69 per hour
Saving of rectifier over motor generator ..... $0.60 per hour

If 20-hour per day operation is considered normal, then total saving of rectifier over motor generator per year is 20 × 365 × 0.60 = $4380.00

CASE 2

Same as Case 1, except cost of power 1.5c per kwh.

MOTOR GENERATOR

Operating cost (power only) 143 × $0.015 = ... $2.15 per hour

RECTIFIER

Operating cost, power 106 × $0.015 = ... $1.56 per hour
Operating cost, tubes = ... 0.51 per hour

Total cost of rectifier ..... $2.07 per hour
Saving of rectifier over motor generator:
Per hour ..... $ 0.08
Per year 584.00

CASE 3

Source ..... direct current
Installation ..... ashore
Cost of power ..... 1.5c per kwh
Rating of installation ..... 100 kw

MOTOR GENERATOR

Operating cost (same as Case 2) ..... $2.15 per hour

RECTIFIER

An a-c generator must be added.
Output of rectifier ..... 100 kw
Efficiency of rectifier (Case 1) ..... 94 per cent
Efficiency of d-c to a-c motor generator ..... 93 per cent
(See original cost data above).
Over-all efficiency d-c line to rectifier output 0.94 × 0.93 = ... 84.4 per cent
Input to d-c to a-c motor generator 100/0.874 = ... 114 kw
Operating cost:
Power—114 × 0.015 = ... $1.71 per hour
Tubes ..... 0.51 per hour

Total ..... $2.22 per hour

From the consideration of these three cases it is seen that the cost of operation of a rectifier including replacement of tubes is less than that of a motor generator. Even in the most unfavorable case where an extra d-c to a-c motor generator is necessary for the rectifier and the cost of power low, the cost of operation of the rectifier is about the same as that of the motor generator. The above figures are based on a tube life of 1000 hours ,whereas the life obtained in service is usually in excess of 2000 hours.

Existing Policy Regarding Choice of Supply

The considerations outlined in the preceding paragraphs, particularly as applying to the older types of tube rectifiers, were responsible for the policy which has guided the Navy in its choice of plate supply. Up to the present time, this policy has been to use motor generators for all shipboard installations. Experience has demonstrated that the motor generator is an extremely satisfactory and reliable source of power for the plate supply at the voltages ordinarily required for use on shipboard. There are at present in use on Naval ships, a large number of such motor generators for transmitters of low to medium power, operating on medium and high frequencies. Many of them have been in use for several years, and the number of motor-generator failures are remarkably low. It was at first considered necessary to supply duplicate radio motor generators, and later it was found that a spare armature sufficed. More recently it has been found that except in the case of the larger ships, where they are considered as insurance, it is unnecessary to provide more than a small number of spare armatures on each tender.

Now, however, when the hot-cathode mercury-vapor tube is demonstrating its advantages and economy, the matter of a combined power supply for radio is being given careful study, and it is expected that experimental installations will be developed and given a service trial in the near future.

At shore stations of the Navy, transmitters of intermediate frequencies up to 2-kw antenna power, and of high frequencies up to 10-kw antenna power, motor generators ranging in voltage from 1000 to 10,000 volts have usually been employed for plate supply. On shore stations equipped with transmitters of higher power than these, rectifiers have been used. Most of these rectifiers are of the thermionic tube type (space was not such a vital consideration), but the latest transmitters, and those now being delivered under contract, are equipped with the hot-cathode mercury-vapor tube.

Some of the high-powered stations using large tube rectifiers are Arlington, Guantanamo (Cuba), Cayey (Porto Rico), Annapolis, San Francisco, San Diego, and Puget Sound. At shore stations both motor generators and rectifiers appear to be equally reliable, and extremely few failures (other than tube failures) have been experienced with either type. Because of the obvious advantages in regulation, efficiency and cost, the mercury-vapor tube is gradually replacing the older type.

In conclusion, the advantages and disadvantages of the two types, as indicated by Naval experience to date, will be tabulated. The rectifier is assumed to use the new mercury-vapor tube.

Motor Generator

ADVANTAGES

1. Smooth variation of output voltage.
2. Good regulation.
3. Small filter system.
4. Few interruptions to service.
5. Low cost of replacements (no tubes).
6. Flexibility; may be mounted wherever convenient space is available.
7. Interchangeability.
8. May be operated directly from d-c lines.
9. Space in radio room is not required for mounting.

DISADVANTAGES

1. Possibility of negative regulation when terminal voltage is lowered.
2. When interruptions occur they usually take longer to repair.
3. Relatively long high-voltage leads between motor generator and transmitter.
4. Rotating machinery with noise, vibration, and bearing troubles.
5. Greater chance of failure due to dirt, oil, water, and it requires more careful attention.
6. Not (usually) directly under observation of operating personnel.
7. Higher first cost and probably higher operating cost.
8. Lower electric efficiency.

Rectifier

ADVANTAGES

1. Positive regulation at any available terminal voltage.
2. Less liability of vital failures.
3. Can be incorporated in radio transmitter thus reducing high-voltage leads to minimum, with consequent greater safety to personnel and less danger of causing explosions.
4. Can operate from a rugged source of power which might be universal for all transmitters.
5. Lower first cost and probably lower operating costs.
6. Has no rotating parts in itself and no high-voltage commutator.
7. Control and operation are under observation of transmitter operating personnel.

DISADVANTAGES

1. Periodic interruptions to service (tube failures).
2. Fragility of tubes and numerous replacements necessary to carry.
3. High cost of replacements.
4. Larger filter system.
5. Requires more space in radio room.
6. Will not operate on the normal electric supply on shipboard, hence requires a separate a-c turbo generator or motor generator.

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HOT-CATHODE MERCURY-VAPOR RECTIFIER TUBES

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Summary—*High-voltage d-c power for radio transmitters has usually been obtained from d-c generators or through rectification of alternating current by means of high-vacuum tube rectifiers or mercury-arc rectifiers. A new type of rectifier tube is described which combines the advantages of the high-vacuum tube with the low and nearly constant arc-drop of the mercury-arc rectifier. Typical tube characteristics and the method of operation are discussed.*

A method is given for rating rectifier tubes in terms of the fundamental limits of the tube, that is, peak inverse voltage and peak plate current.

Single-phase and three-phase circuits are shown for use with the hot-cathode mercury-vapor tube.

General

THE problem of supplying a constant high voltage to the plate circuits of transmitting sets has been previously met by the use of d-c generators, high-vacuum tube rectifiers and mercury-arc rectifiers. Direct-current generators have been widely used in the moderate voltage fields and to some extent in the higher voltage fields. Vacuum tubes for the rectification of high-voltage alternating current have found increasing favor in the higher voltage fields because of their reliability of operation and performance. The mercury-arc rectifier has found more favor in European transmitter design than in American—the general practice being to connect several units in series in order to obtain the required output voltage. This paper describes a new type of rectifying tube which combines the high-voltage qualities of the vacuum tube with the efficiency and constant tube drop of the mercury-arc rectifier.

The new tube may be described as a gas-filled thermionic rectifier tube having a low and practically constant arc-drop while carrying current, and capable of withstanding high inverse voltages. The idea of introducing a gas into thermionic tubes in order to neutralize the space charge is old, but with the exception of the "tungar" rectifier there seems to have been only a limited application of that idea. The tungar rectifier is filled with gas at a high pressure (3–5 cm Hg) and can only operate at low voltages. The new type of tube operates in the presence of gas at a low pressure (1–30 microns Hg) and is capable

* Dewey decimal classification: 621.313.73. Presented before New York meeting of the Institute, September 4, 1929.

of operating at relatively high voltages. The presence of gas at high pressure gives adequate protection from cathode evaporation and the more serious trouble, cathode disintegration by positive ion bombardment. At low pressures, this protective action against cathode evaporation is negligible, and the successful development of the high-voltage tubes results from the discovery by Dr. A. W. Hull[1] that cathode disintegration may be completely avoided if the arc-drop is maintained below a definite critical value. For most of the common inert gases the critical value of arc-drop at which the positive ions acquire sufficient kinetic energy to destroy the cathode lies between 20 and 25 volts.[2] In the developed tube, mercury vapor has been introduced to provide the gas for neutralization of the space charge.[3] The ionization potential of mercury vapor is 10.4 volts,[4] and the arc-drop of the tube is approximately 15 volts, which is well below the critical disintegration value (i.e., 22 volts for Hg vapor).

The operation of the hot-cathode mercury-vapor rectifier tube is similar in several respects to that of the mercury-arc rectifier. In the mercury-vapor tube electrons are drawn from a heated cathode on the positive part of the cycle and these electrons in colliding with mercury molecules cause the vapor to ionize. In the mercury pool tube electrons are drawn from a cathode spot on the surface of the mercury to the anode, and these in colliding with mercury molecules cause the vapor to ionize as before. Both tubes exhibit the blue glow that is associated with ionized mercury vapor. On the negative or inverse part of the cycle when the anode becomes negative with respect to the cathode, electron current ceases and the glow completely dies out in the mercury-vapor tube. When the anode becomes negative in the mercury pool tube, electron current ceases and the glow around that anode dies out, but since it is necessary to maintain the cathode spot by auxiliary holding anodes, ionization is held in the body of the tube throughout the inverse cycle. In both types of tubes, the current which may be drawn is determined by the electron emission of the cathodes, but in the pool tube the amount of emission depends upon the size of the cathode spot which is determined by the current through the tube.

[1] A. W. Hull and W. F. Winter, "The volt-ampere characteristic of electron tubes with thoriated tungsten filaments containing low pressure inert gas," *Phys. Rev.*, 21, 211, 1923 (abstract).

[2] A. W. Hull, "Gas-filled thermionic tubes," *Trans. A.I.E.E.*, 47, No. 3; July, 1928.

[3] K. H. Kingdon, "Neutralization of electron space charge by positive ionization at very low gas pressures," *Phys. Rev.*, 21, p. 408; April, 1923.

[4] I. Langmuir, "Positive ion currents from the positive column of mercury arcs," *Science*, 58, No. 1502, pp. 290–291, Oct. 12, 1923.

Comparison With High-Vacuum Rectifier

Perhaps the clearest description of the mercury-vapor tube may be gained from a comparison of its characteristics with those of the high-vacuum rectifier. The most striking difference between the two types is in the tube-drop. In the high-vacuum tube, electrons are drawn from a heated cathode and these in the passage to the plate build up a space-charge voltage-drop which depends upon the current drawn, element spacing, and so forth, and which may vary in magnitude from a few volts to several thousand. In the mercury-vapor tube the space charge is limited by the arc-drop of the vapor, which is practically constant at values between 12 and 17 volts regardless of the current drawn. The cathode for the higher power vacuum tubes is usually of the tungsten filament type which for equivalent emission and life requires approximately ten times the heating power of the oxide-coated or "Wehnelt" cathodes of the mercury-vapor tubes.

As a direct comparison we may consider the advantages which the hot-cathode mercury-vapor tube rectifier has over the high-vacuum tube rectifier. They are

(1) improved regulation of voltage output
(2) efficiency
(3) cost

Since the tube-drop is practically constant, the regulation of the voltage output is that of the transformer, supply, and circuit. Overall regulation as low as 8 per cent has been obtained with mercury-vapor tubes operating in a three-phase full-wave circuit (to be described later) while that of the vacuum-tube rectifier is usually from 15 to 20 per cent. As a comparison of tube efficiencies, we may consider six UV-214 high-vacuum water-cooled tubes operating in the usual three-phase, double-wye parallel circuit, and six UV-857 mercury-vapor tubes (which will be described later) operating in the three-phase full-wave circuit. Each circuit gives a wave form having a six-phase ripple. We may assume that a choke sufficiently large to give a square current wave through the rectifier precedes any capacitance in the filter circuit. The UV-214 rectifier under normal operating conditions will deliver a d-c output of 12 amperes at 15,000 volts. The space-charge loss at this output is approximately 18.7 kw and the filament power is 6.9 kw. (In the three-phase double-wye circuit the load current divides equally between the two wyes. Consequently, the space-charge loss which is due to a space-charge drop of approximately 1560 volts at 6 amperes is $2(1{,}560 \times 6) = 18.7$ kw). The UV-857 rectifier will supply the same output with a tube-drop loss of approximately

0.36 kw and a filament power of 1.80 kw. (In the three-phase full-wave circuit two tubes in series carry the full load current. The tube-drop loss is therefore the arc-drop of two tubes times the load current or $30 \times 12 = 0.36$ kw). The tube efficiency output divided by output and losses in the first case is 87.5 per cent and the second 98.8 per cent or a gain of 11.3 per cent for the mercury-vapor rectifiers. At 20,000 volts, the UV-857 rectifier will give a d-c output of 400 kw with a tube efficiency of 99.4 per cent. Table I gives the comparative figures on the operation of mercury-vapor and high-vacuum tubes.

TABLE I

COMPARISON OF HIGH-VACUUM AND MERCURY-VAPOR TUBE RECTIFIERS

No. of Tubes	Radiotron	Circuit	D-C Output volts	amps	kw	Tube-Drop volts	at amps	Losses Filament	Tube-Drop	Efficiency
6	UV-214	3φ double Y	15000	12	180	1560	6	6.9 kw	18.7 kw	87.5 per cent
6	UV-857	3φ full wave	"	"	12	15	12	1.8 "	0.36 "	98.8 per cent
*6	UV-857	3φ " "	19100	20	382	15	20	1.8 "	0.6 "	99.4 per cent

* Maximum rating

The initial cost of the mercury-vapor tube rectifier is less for an equivalent rating than that of the high-vacuum tube rectifier. A power distribution transformer of standard design may be used in the three-phase full-wave circuit which is the most common one for the mercury-vapor tubes. The utilization factor[5] or the ratio of the transformer capacity when used for rectification purposes to the a-c capacity for the same temperature rise is approximately 96 per cent. The high-vacuum tube, in general, requires a special transformer whose secondary is subdivided, and the coils interlaced to reduce d-c saturation. For the double-wye circuit, the utilization factor is only 68 per cent, that is, the secondary of the special transformer would require 47 per cent more capacity than would be needed for an a-c load of the same capacity. In addition, the voltage and rating of the special transformer would have to be greater in order to compensate for the tube space-charge drop. For low-power outputs neither type of tube requires special cooling other than free-air circulation, but for the higher power outputs the high-vacuum tube requires a cooling medium, usually water, and the additional equipment necessary to provide a reliable and pure supply.

TEMPERATURE LIMITS

There are two definite temperature limits which govern the operation of the mercury-vapor tube. The minimum temperature corresponds to the vapor pressure of the mercury at which the arc-

[5] D. C. Prince, "Rectifier wave forms," *G. E. Rev.*, 27, 1924, p. 608.

drop begins to exceed the critical value for cathode disintegration. The maximum temperature corresponds to the vapor pressure of the mercury at which breakdown or arc-back occurs on the inverse part of the cycle. The vapor pressure in the tube is determined by the temperature of the coldest part of the bulb. Mercury condenses at this point in the form of small drops and a measurement of the bulb

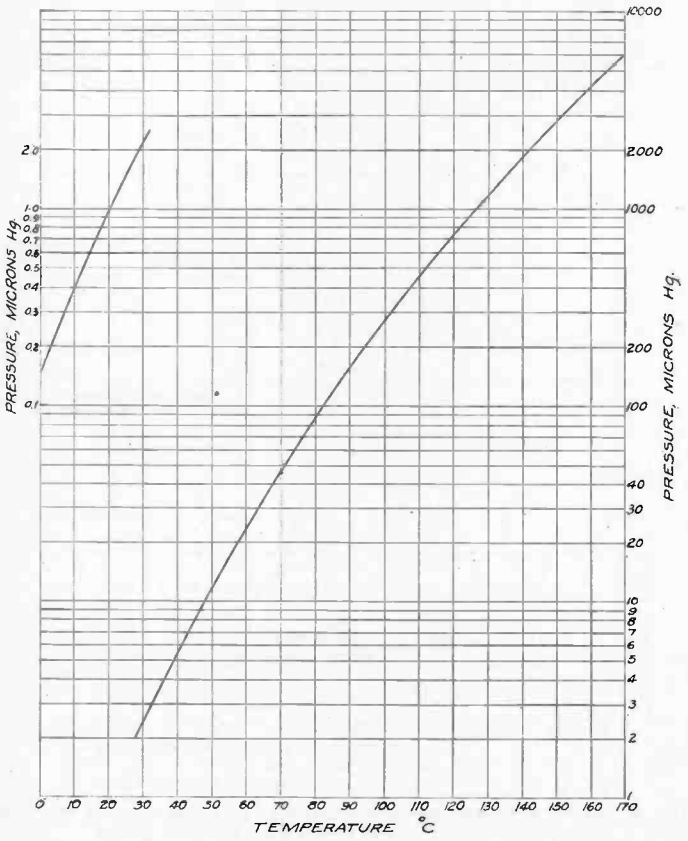

Fig. 1—Pressure and temperature of saturated mercury vapor.

temperature (the drop through the glass being negligible) gives an accurate means of determining the vapor pressure. In Fig. 1 the pressure and temperature of saturated mercury vapor is given.

The arc-drop, or tube-drop, as a function of mercury temperature is shown in Fig. 2. Within the limits of the present design this drop is practically independent of the size of the bulb and the electrode spacing. For mercury temperatures below 15 deg. C, which cor-

responds to ambient temperatures below 0 deg. C, the arc-drop begins to exceed the critical disintegration value. In the case of a thoriated tungsten filament, as an electron-emitting cathode, in a gas where the active material is a monatomic layer of thorium, a slight increase of arc-drop above the critical value will immediately deactivate the filament.[2] In the case of the oxide-coated filament the active material has appreciable thickness and it is therefore possible to operate for

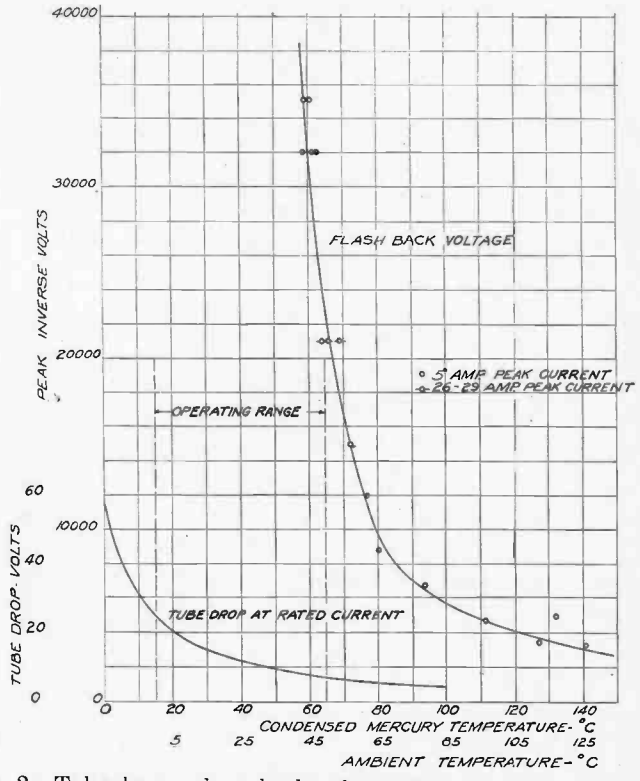

Fig. 2—Tube-drop and arc-back voltages as a function of mercury temperature for the UV-869 and UV-857 tubes.

some time with an arc-drop above the critical value, but such operation results in cathode disintegration and consequent short life. High mercury temperatures decrease the arc-drop and are favorable for long cathode life.

The arc-back curve shown in Fig. 2 represents the peak inverse potentials at which breakdown occurs as a function of the mercury temperature. The data were taken by gradually increasing the ambient temperature while the tubes (UV-869 and UV-857) were operating as

rectifiers under full load conditions. The difference of 15 deg. C between the ambient temperature and condensed mercury temperature represents the designed temperature rise of the coldest part of the bulb above ambient. In Fig. 3 the flash back voltages for the UX-866 and UV-872 Radiotrons are given. These tubes are smaller and the arc-back voltages are lower than in Fig. 2.

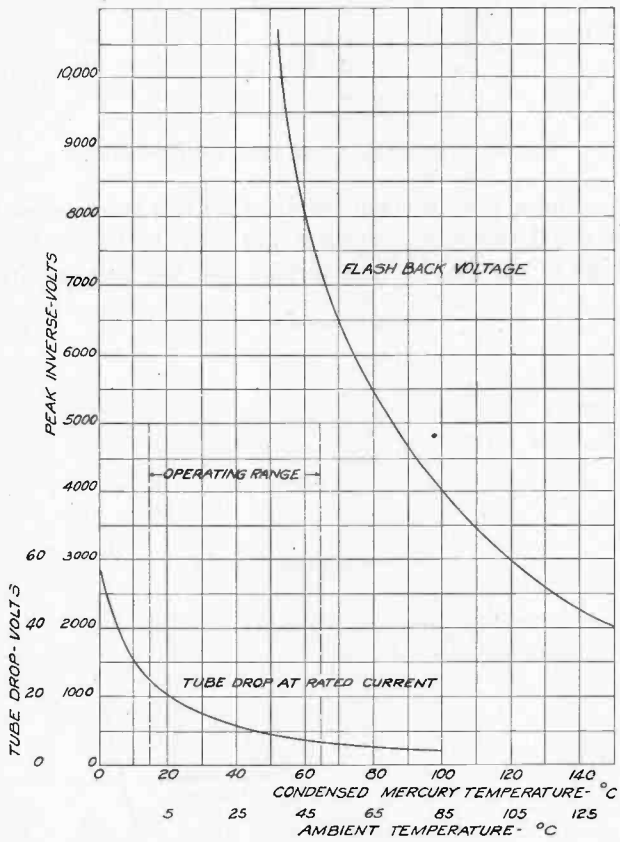

Fig. 3—Tube-drop and arc-back voltages as a function of mercury temperature for the UX-866 and UV-872 tubes.

Tube Ratings

There are two fundamental tube limits which determine the power output that can be obtained from any number of tubes operating in any type of circuit. These ratings are:

(1) maximum peak inverse voltage at which the tube can operate without flashing back,

(2) maximum peak plate current which the cathode can furnish with a reasonably long life.

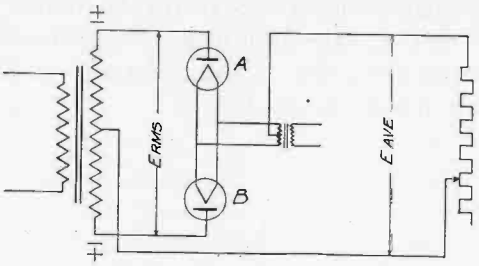

Fig. 4—Single-phase full-wave rectifier circuit.

The maximum peak inverse voltage that can exist across a tube in any of the usual types of circuits is equal to the line-to-line peak or crest voltage of the power transformer less the voltage drop of the

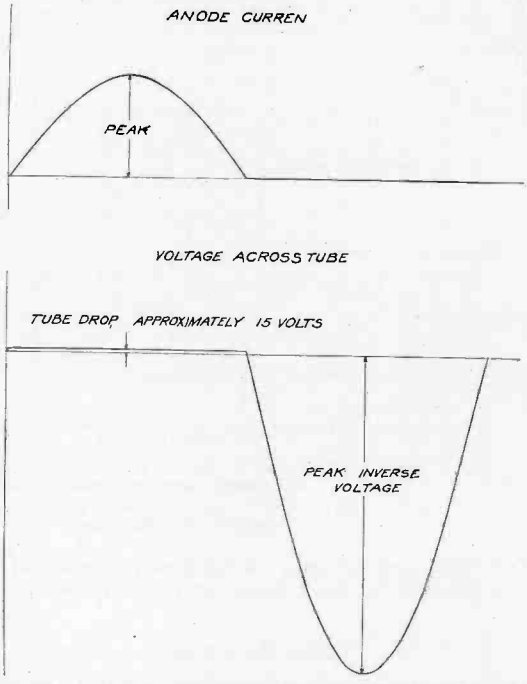

Fig. 5—Voltages and current conditions for tube *A* of the single-phase rectifier circuit shown in Fig. 4.

conducting tube. If we consider tube *A* in the single-phase full-wave rectifier circuit shown in Fig. 4 to be carrying current, its cathode is

practically at the positive potential of the transformer secondary since the arc-drop for the mercury-vapor tubes is so small that it may be neglected. The cathode of tube *B* is connected to the cathode of *A*, but the anode of tube *B* is connected to the negative end of the transformer secondary. Therefore, the full secondary voltage (*Erms*) is impressed across tube *B*, and the crest is the peak inverse voltage. On the last half of the cycle the transformer polarity reverses and tube *B* carries the current, while the peak inverse voltage builds up across *A*.

The peak plate current depends upon the type of circuit, tube, filter, and load. In the single-phase full-wave circuit each tube must carry the full load current for half of the time. In the three-phase half and full-wave circuits each tube carries the load current for one-third of the time. If we consider a single-phase full-wave rectifier operating with mercury-vapor tubes and supplying a resistance load, the peak plate current is simply the maximum of the sine wave which averages to give the d-c ammeter reading. If sufficient inductance is placed in series with the load square blocks of current are drawn from the rectifier and the peak plate current approaches the d-c output current. When a condenser is placed across the rectifier output, plate current is drawn for only a part of the half-cycle, and the peaks may reach values of from three to five times that of the average or d-c load current. In high-vacuum tubes the peak current is usually limited by the definite emission limitation of the pure tungsten filament. The mercury-vapor tube in itself has not the same current limiting characteristic, and the value of the peak plate current will depend upon the transformer leakage reactance, the capacity of the condenser, and the load. Wherever possible, a small inductance should precede any condenser in the filter circuit. When special load requirements prohibit the use of an inductance, the output should be reduced to conform to the peak current rating of the tube. Oscillograms of the peak currents for various filter conditions are shown later in Fig. 10.

In connection with peak currents, it is well to consider the effect of short circuiting the rectifier output, and also, the effect of arc-backs. The mercury-vapor tube in itself possesses no definite current limiting characteristic. The arc-drop is practically constant and independent of the current, and the cathode is capable of supplying transient emission currents which are greatly in excess of the rating. In the first case, the secondary is in effect short-circuited and the short-circuit current is limited only by the resistance and leakage reactance of the transformer. The short-circuit impedance of power transformers is usually of the order of 5 to 10 per cent of the rated impedance, which means that the magnitude of the short-circuit current may reach

values of 20-10 times normal. Ordinarily, the filter and power supply will increase the effective impedance somewhat and so limit the short-circuit current still more. Small high-voltage transformers, in general, have a rather high impedance and the short-circuit current is relatively low. The effect of arc-back in one or more tubes is essentially the same as that of short circuiting the rectifier output.

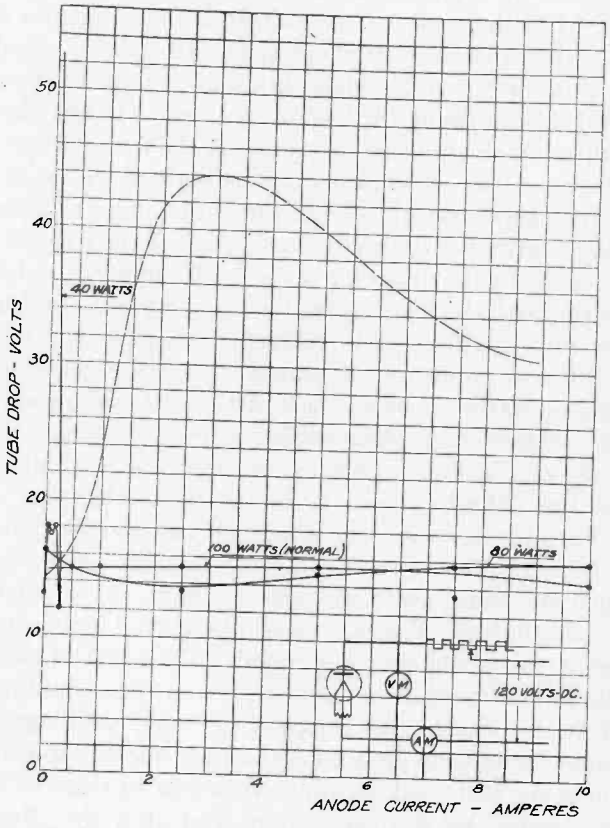

Fig. 6—Cathode emission characteristics as a function of arc-drop with constant mercury temperature (UV-869).

The mechanism of arc-back or flash back has been fully described in investigations of the mercury-arc rectifiers[6,7] and will not be taken up here.

[6] D. C. Prince, "Mercury arc rectifier phenomena", *Journ. A.I.E.E.*, 46, 667, 1927.

[7] D. C. Prince and F. B. Vogdes, "Mercury arc rectifiers and circuits, 1927," McGraw-Hill Book Company.

The Cathode

The cathode is one of the most important factors in the design of a mercury-vapor tube. In order to keep the arc-drop below the disintegration value, the cathode must be capable of supplying the full anode current demand by electron emission. At the low-vapor pressures required for high-voltage operation there is very little protective

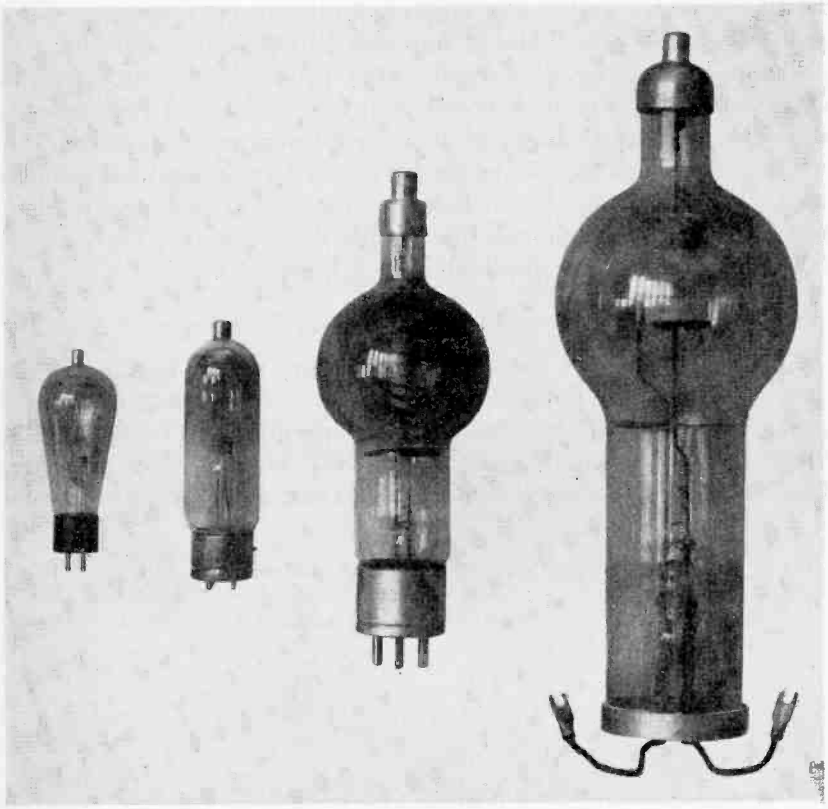

Fig. 7—Hot-cathode mercury-vapor rectifiers. Radiotrons UX-866, UV-872, UV-869, UV-857.

action against cathode evaporation and the entire function of the gas becomes that of neutralizing the space charge.

The curves shown in Fig. 6 represent the emission characteristics of a UV-869 tube for various filament temperatures with constant mercury temperature (30 deg. C). The emission limit as indicated by the arc-drop was not reached with 100 watts, which is the normal heating power of the filament, or with 80 watts for anode currents of twice

normal rating. In the 80-watt curve, however, hot-spotting began to appear. As the anode current is increased the arc-drop is subject to abrupt changes of one or two volts in either direction. These points are not reproducible and are probably due to the formation or burning out of active craters. Smooth curves are therefore drawn as representative of the average tube-drop. In the 40-watt curve a crater was formed and then deactivated. If this tube had been operated in a high-voltage rectifier set with such a low-filament temperature, sputtering would probably have taken place giving rise to high-speed electrons and probable puncturing of the bulb. The broken curve represents an experimental tube having a poorly activated filament. In this case the tube-drop increased rapidly until an equilibrium point was reached at which the positive ion bombardment of the filament and the radiated energy from the arc stream became sufficient to raise the filament temperature and so increase the supply of electrons. The life of a tube operating with such a high drop is short.

Hot-Cathode Mercury-Vapor Radiotrons

Fig. 7 shows the hot-cathode mercury-vapor Radiotrons[8] as developed for radio power supply purposes. The ratings in terms of peak inverse voltage and peak current are given in Table II. The lower voltage tubes, UX-866 and UV-872, are capable of supplying bias and plate power for the intermediate stages of commercial broad-

TABLE II
Hot-Cathode Mercury-Vapor Tube Ratings

Radiotron	Filament volts	Filament amps	Peak Inverse Voltage	Peak Anode Current (amperes)
UX-866	2.5	5	5000	0.6
UV-872	5	10	5000	2.5
UV-869	5	20	20000	5.0
UV-857	5	60	20000	20.0

casting transmitters. In addition, they furnish an excellent means of obtaining rectified power at potentials up to 5000 volts and currents up to 2.5 amperes. The UX-866 was especially designed for furnishing a plate power supply for the amateur transmitter. The higher voltage tubes UV-869 and UV-857, properly grouped, will supply rectified power outputs of about 100 and 400 kw, respectively, at approximately 20,000 volts direct current. At the present time this amount of power is sufficient for the final output stages of most transmitters.

[8] Manufactured jointly by the General Electric and Westinghouse Companies for the Radio Corporation of America.

Circuits

The circuits most commonly used with the mercury-vapor tubes are shown in Fig. 8. The single-phase full-wave and the three-phase

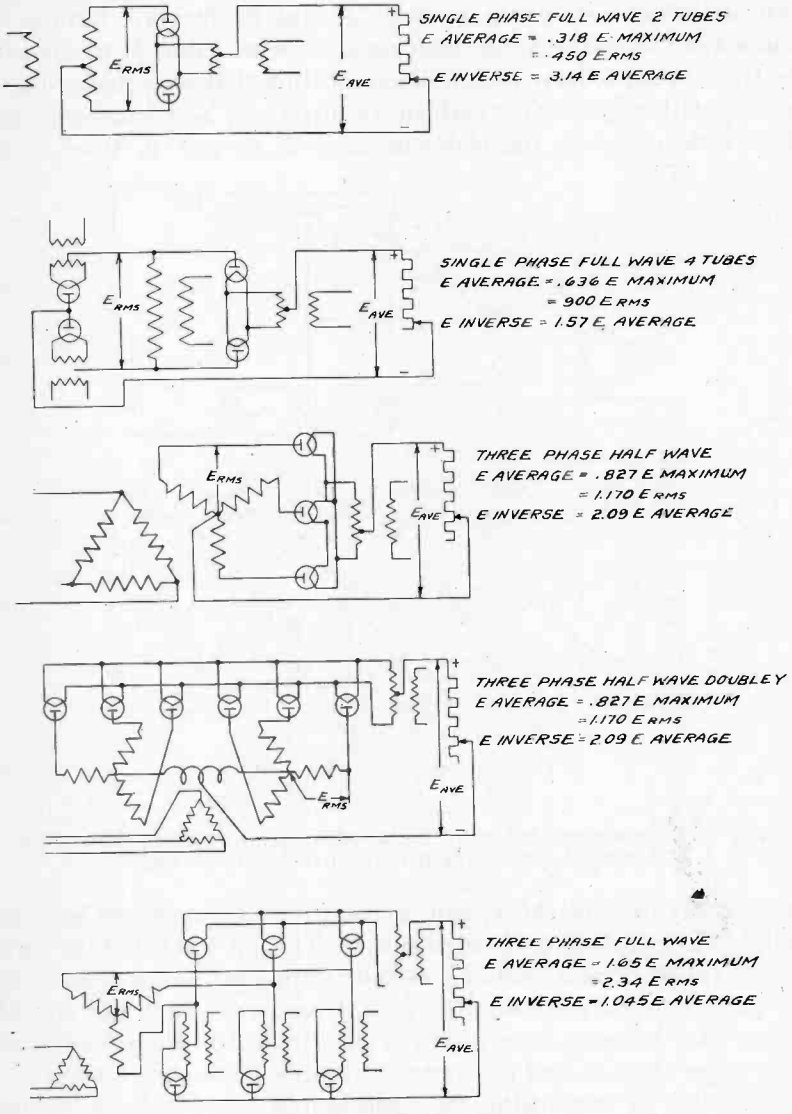

Fig. 8—Circuits for hot-cathode mercury-vapor tubes.

half-wave circuits are widely used and need no further explanation. The three-phase full-wave circuit, however, is new. It was suggested

by D. C. Prince as being particularly applicable to the half-wave mercury-vapor tube. From the tube standpoint it possesses the decided advantage of giving a peak inverse voltage whose magnitude is only 4.5 per cent greater than the average output voltage. The wave form is that of a six-phase rectifier. In Fig. 9, the wave form is developed and the current transfer for each tube indicated. If we consider the transformer to have such a phase rotation that *oa* is just swinging positive with respect to the cathodes of tubes 1, 3, and 5 and *oc* is negative with respect to the plates of tubes 2, 4, and 6, tube 3 will

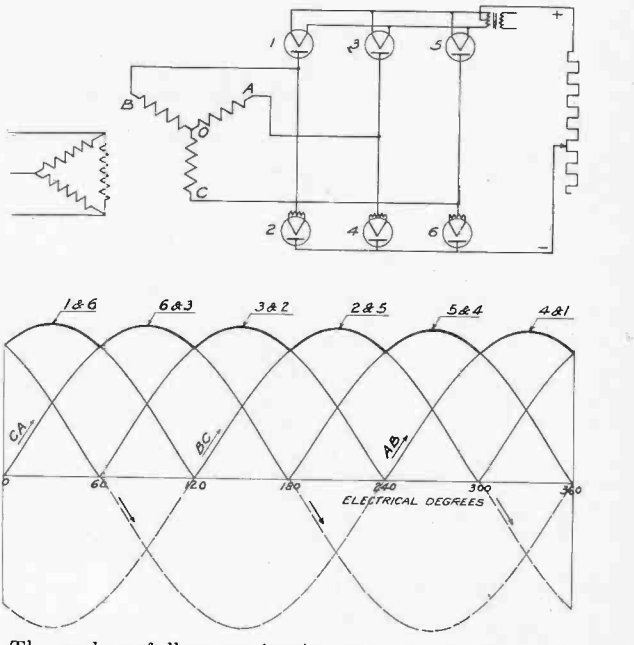

Fig. 9—Three-phase full-wave circuit with output voltages developed and current conducting period for each tube indicated.

start rectifying and the circuit is completed through the load and back to the transformer through tube 6. The full voltage of the transformer (peak inverse voltage) is thus impressed across tubes 4 and 5. Sixty electrical degrees after tube 3 begins to carry current, the voltage of *ob* becomes more negative with respect to the plates of the lower tubes than *oc*, and the current transfers from tube 6 to tube 2. One method of visualizing the operation is to consider a triangle revolving about a center which can move vertically but not horizontally, and between a fixed and movable plane. The movable plane will describe the voltage output of the circuit. The circuit possesses the

further advantage that there is no d-c saturating current in the windings of the transformer and that the transformer utilization factor is higher (approximately 96 per cent) than for any other type of rectifier circuit.

If voltages higher than the tube ratings are desired, units may be connected in series. Higher currents may be obtained by connecting units or tubes in parallel through current dividing reactors.

The oscillograms, Fig. 10, represent the voltage and current conditions for a three-phase full-wave rectifier supplying a resistance load with (1) no filter, (2) an inductance filter, (3) a condenser filter. The peak currents are somewhat less in this case than for the single-phase full-wave circuit shown in the next graph (4). The last oscillogram (5) shows the voltage across one tube in the three-phase full-wave circuit. (The oscillograms were retraced to facilitate reproduction by photo engraving.)

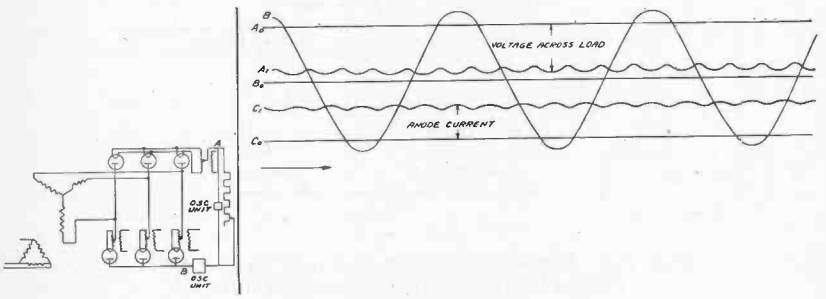

Fig. 10a—Output voltage and current of a three-phase full-wave rectifier with a resistance load.
Curve A_1—voltage across load
Curve B—timing wave, 60 cycle
Curve C_1—anode current

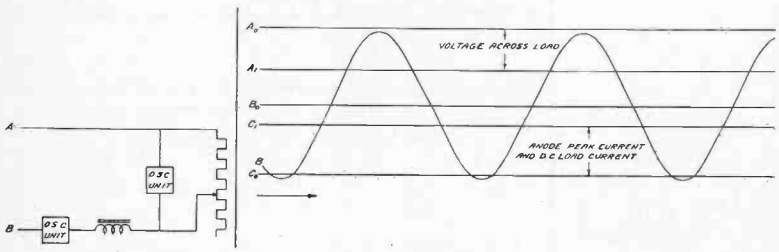

Fig. 10b—Output voltage and current of a three-phase full-wave rectifier with an inductance filter.
Curve A_1—voltage across load
Curve B—timing wave, 60 cycle
Curve C_1—anode current

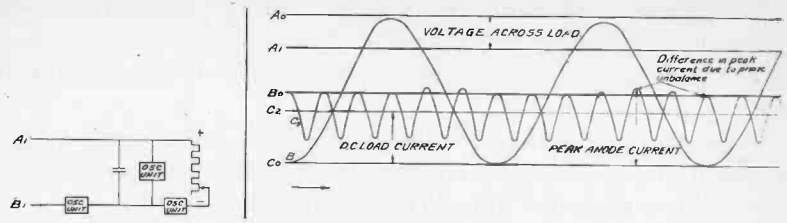

Fig. 10c—Output voltage and current of a three-phase full-wave rectifier with a condenser filter.

Curve A_1—voltage across load
Curve B—timing wave, 60 cycle
Curve C_1—anode current
Curve C_2—d-c load current

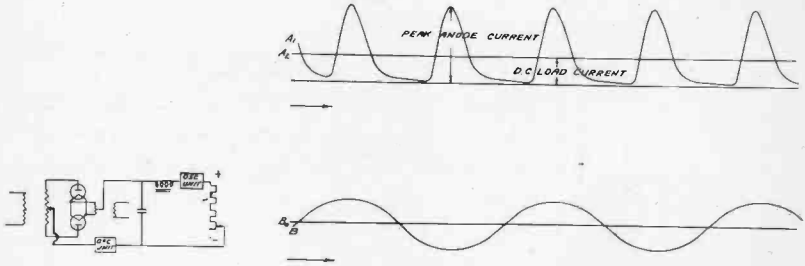

Fig. 10d—Output voltage and current for single-phase full-wave circuit with a condenser filter.

Curve A_1—anode current
Curve A_2—d-c load current
Curve B—timing wave, 60 cycle

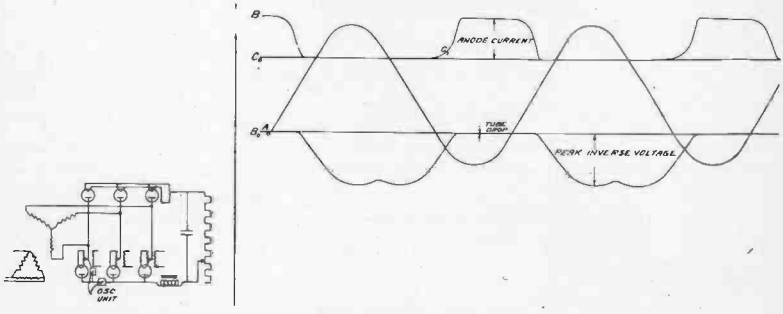

Fig. 10e—Tube-drop and peak inverse voltage across one tube in a three-phase full-wave circuit.

Curve A_1—voltage across one tube
Curve B_1—timing wave, 60 cycle
Curve C_1—anode current through one tube

In conclusion, the authors wish to express their appreciation of the assistance given them by the staff of the Research Laboratory, but especially for the counsel and guidance of Dr. A. W. Hull, Dr. F. R. Elder, D. C. Prince and O. W. Pike.

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Proceedings of the Institute of Radio Engineers
Volume 18, Number 1 *January, 1930*

Discussions on
HOT-CATHODE MERCURY-VAPOR RECTIFIER TUBES*

H. C. STEINER AND H. T. MASER

and

PLATE-VOLTAGE SUPPLY FOR NAVAL VACUUM-TUBE TRANSMITTERS*

E. C. RAGUET

H. E. Hallborg:[1] Some practical problems of control and installation arise in connection with the use of high-voltage rectifiers, particularly the hot-cathode mercury-vapor rectifier, a few of which will be cited.

It has been found most practical in high-power, short-wave installation to mount the rectifier equipment in the basement, and the radio-frequency equipment on the floor above. This arrangement is in line with motor-generator practice where the rotating equipment is commonly remotely located from its load.

The various operations of starting and stopping, and change of voltage tap must consequently be performed by remote control. Filament control is obtained by contactors operated by push buttons from the floor above, with various position indicator lights, including a reduced voltage position so that low voltage may be placed on the tubes when starting. A drum switch on the power amplifier panel on the upper floor operates a series of magnetic contactors which change the rectifier transformer taps, thus affording flexible means of changing plate voltage.

The bringing of the output voltmeter and ammeter leads within range of the operator on the upper floor requires that the leads be protected against high voltage due to an open circuit which might result in danger to the personnel or equipment. This detail is taken care of by providing a gas-filled protector tube which will connect the open lead to ground if the voltage builds up in excess of the glow voltage of the tube.

The demand for protection to the rectifier tubes against overloads or improper operation is also an operating consideration. The rectifier equipment is entirely enclosed in a metal grille provided with access doors, so interlocked that the opening of any door automatically functions to remove all dangerous voltages. A control is also provided in the plate-voltage shifting process so that no damage is done to the switch contacts due to shifting voltage under power.

I had the pleasure recently of meeting a representative of a British tube manufacturing company who had spent several months in this country visiting the various radio plants and tube factories. When he was about to leave for England, I asked him if he carried back with him any outstanding impressions of American radio development. He replied without a moment's hesitation, "Yes—it is your development of the hot-cathode mercury-vapor tube."

W. C. White:[2] In the first paper this evening, mention was made of interruption of service due to tube failures as among the disadvantages of the rectifier. In the case of the hot-cathode mercury-vapor tubes there is a point of advantage relative to the high-vacuum type. By means of the color, and shape of the glow

* Presented before New York meeting of the Institute, September 4, 1929.
[1] R. C. A. Communications, Inc., 66 Broad Street, New York, N. Y.
[2] Research Laboratory, General Electric Co., Schenectady, N. Y.

inside the tube a failure may often be predicted or seen somewhat ahead of time.

For instance, if the vacuum is slightly impaired, due to the cracking of the glass from some accidental cause or impairment of vacuum due to overload, a person experienced in operating the tubes will often be able to tell that something is the matter and that the life of the tube is approaching its end. In the case of a tube failure from one cause or another, the shape of the glow in the particular tube often is characteristic of the nature of the trouble. It is a thing that cannot be easily described, but to one who has operated these tubes a good deal this color and shape of the glow tell quite a story.

One other point: If in certain applications it is very essential to prevent failures during operation it is possible by a simple testing apparatus to test the tubes at intervals, and by keeping track of the readings predict failures in those cases a few hundred hours ahead. Of course, this is not always possible, but by means of these two points I have brought out, failures of tubes and interruption of service can be reduced to a rather small minimum.

R. M. Arnold:[3] I believe there is one economic factor which has been disregarded in the comparison of the relative costs of motor-generator plate-current supply vs. rectified alternating current. It is my understanding that the costs of the rectifiers include the filter system, while those on the motor generator do not. If this is taken into account, the case for the rectifier becomes more favorable.

Another point was, in the case of the C. G. Navy specification tube mentioned in the first paper, which was giving a life of 2500 hours and an expectation of 5000 hours on the 22-volt tube, that tube, I believe, was a high-vacuum tube, because insofar as I know, the hot-cathode mercury-vapor tube has to have a filament whose peak voltage is less than the ionization voltage of the mercury vapor. I believe the mercury-vapor tube will show considerably better life under their normal rating than the high-vacuum tube.

W. C. White: The 22-volt tube was a high-vacuum tube. You are correct in assuming that the voltage has to be low across the filament of the hot-cathode mercury-vapor tubes. As far as its life goes, it is expected and hoped that some tubes will last 20,000 hours, but 20,000 hours is about three years' service, and they are not that old yet.

Frank R. Stansel:[4] What is the routine test suggested for locating the end of the mercury-vapor life?

H. C. Steiner:[5] The routine test, or rather the test which Mr. White mentioned, in general, consists of measuring the arc-drop of the tube at something like double current rating. That is, with a d-c potential applied to the plate of the tube and sufficient series resistance to limit the plate current to double rating, the arc-drop should not under equilibrium conditions exceed 18 to 20 volts. If the arc-drop is very much above this (i.e., 22-24 volts) one may consider that the tube is reaching the end of its life.

A second method which is perhaps more accurate is to measure the peak-voltage drop across the tube by means of a peak-reading voltmeter while the tube is operating. This requires special equipment and for high-voltage work is a little more difficult than the d-c measurement.

[3] Sanderson and Porter, 52 William Street, New York, N. Y.
[4] Bell Telephone Laboratories, 463 West St., New York, N. Y.
[5] Research Laboratory, General Electric Co., Schenectady, N. Y.

R. M. Arnold: In the design of power rectifiers in these tubes the point was brought up that the standard distribution transformers could be used. Does that mean that no regard should be given in the transformer to the d-c polarizing?

H. C. Steiner: The absence of a d-c saturating or polarizing current in the case of the three-phase, full-wave circuit is one of the advantages of the circuit. In operation, current is carried for a third of a cycle in one direction by the transformer winding which is most positive and in the opposite direction for a third of a cycle when the polarity of the winding reverses. Consequently, as far as the transformer is concerned we are supplying an a-c load, and standard distribution transformers may be used.

R. M. Arnold: D. C. Prince, in one of his previous papers on high-vacuum rectifiers, made the point, as I remember it, that the shell-type three-phase transformer was the only type of construction which would give him the desirable feature of the polarizing. Is that still desirable in the case of this tube?

H. C. Steiner: I believe that Mr. Prince was referring to the three-phase, half-wave circuit which is commonly used in high-vacuum tube rectifiers. In that case, each winding carries current in only one direction, and therefore some means must be taken to prevent d-c saturation.

The use of mercury-vapor tubes would not help saturation since it is inherent in the type of circuit.

Austin Bailey:[6] I should like to ask if it is possible to operate these tubes in parallel, and thereby obtain greater output, or whether it is necessary to have the entire conducting path enclosed in a single envelope.

H. T. Maser:[7] It is possible to use these tubes in parallel provided a current dividing reactor is used. The mercury-vapor tubes possess the characteristic of a negative resistance when carrying current, and since the drop across each tube is not exactly the same, a current dividing reactor must be used.

J. G. Nordahl:[8] I should like to ask how to order transformers for rectifier service. When a resistance load is used, the average d-c voltage, the integration under the sine wave divided by the base, is had. When a large inductance is used in the filter, the load current is almost square-topped. This causes commutation, I believe, which causes the average d-c voltage to drop. How would we order transformers for this service?

H. C. Steiner: Ordinarily, we don't pay any attention to the effect of commutation, that is, the short-circuiting of the voltage output through the tubes, when we have an inductance in the circuit. It amounts to a loss, I believe, of a few per cent of what we would get if we calculated the voltage on a straight resistance load basis.

There is one other point which should be considered, and that is the d-c drop across the filter reactors. In small rectifiers where the d-c resistance of the filter reactors may be of the order of 1000 ohms, the voltage-drop is appreciable. In large rectifiers the reactor resistance is low, and the d-c voltage-drop is low. The output voltage is influenced to some extent by the design balance of inductance and capacity in the filter—the effect of capacity being to increase the output voltage.

[6] American Telephone and Telegraph Co., 195 Broadway, New York, N. Y.
[7] Research Laboratory, General Electric Co., Schenectady, N. Y.
[8] Bell Telephone Laboratories, 463 West St., N. Y. C.

J. D. Nordahl: We have had some trouble with that. However, I find that taking into account the drop across the choke coil in a single-section filter, that is, using a choke next to the tube, then a condenser, the drop due to commutation is about 5 per cent, so the transformers have to be ordered about 5 per cent higher. That may be due to the transformers we have.

H. C. Steiner: Are you using a single-phase circuit or the three-phase full-wave circuit?

J. G. Nordahl: I am at present using a three-phase single-wave circuit, but have used various other types of circuits which have not been studied as thoroughly.

H. C. Steiner: I believe that the trouble is probably due to the transformer, that is, the regulation due to the resistance of the windings and the leakage reactance. Also, in the three-phase, half-wave circuit you have the possibility of saturation which would tend to reduce the output voltage.

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NOTE ON THE STABILITY OF BALANCED HIGH-FREQUENCY AMPLIFIERS*

By
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(Research Laboratories, National Carbon Company, Inc., Cleveland, Ohio)

Summary—*The question of stability in a balanced or neutralized radio-frequency amplifier is considered for one stage. Experimental and theoretical curves are given for the amplification including regeneration as the plate to control grid capacity is varied in a balanced or neutralized radio-frequency amplifier.*

The results are discussed for n stages of an impedance coupled amplifier by using the author's general equation for the limit of stable amplification $A_v < \sqrt{2g_m/n\omega C_0}$ *obtained for one stage.*

The desirability of using a new tube factor $\sqrt{g_m/C_0}$ *to compare tubes designed for use in high-frequency amplifiers is also discussed.*

ONE important consideration in the design of neutralized or balanced radio-frequency amplifiers has been neglected in the literature of the art. This consideration is that of designing the amplifier so that it will be stable for the greatest possible variation of the control grid to plate capacity in the tubes used. The reason for neglecting this factor has probably been the difficulty of analyzing the effect of regeneration mathematically. The problem is quite important as the mutual capacity of tubes of the same type varies considerably, and it is desirable to have the amplifier stable with any tube of the same type for which it is balanced.

In a previous paper[1] the author derived an expression for the limit of stable amplification per stage of an n-stage amplifier in terms of the mutal capacity, mutual conductance, frequency and transformer constants. This expression $A_v < \sqrt{2g_m/n\omega C_0}$ shows that for the same amplification the value of C_0 to cause oscillations would vary with the mutual conductance.

In the problem considered here it will be assumed that the value of non-regenerative amplification will not be affected by the addition of the neutralizing or balancing circuit. In practice, the amplifier would be balanced with tubes having close to average values of control grid to plate capacity. In the experimental verification it was necessary to balance the stage and vary the balancing capacity leaving the tube capacity constant. It was assumed that when the balancing capacity was varied a certain percentage the same regenerative am-

* Dewey decimal classification: R132.

[1] J. R. Nelson, "Circuit analysis applied to the screen-grid tube." Proc. I. R. E., 17, 320; February, 1929.

plification would be obtained as if the balancing capacity were left constant and the tube capacity varied the same percentage. The value of C_0 used to calculate the amplification was found by expressing the difference between the capacity required to balance the stage and the capacity used as a percentage and multiplying the control grid to plate capacity of the tube by this percentage.

In the previous paper the results were considered for n stages. In this paper the regenerative amplification will only be calculated and measured for one stage. The behavior of n stages may be found from the results obtained for one stage by using the equations developed in the previous paper.[1]

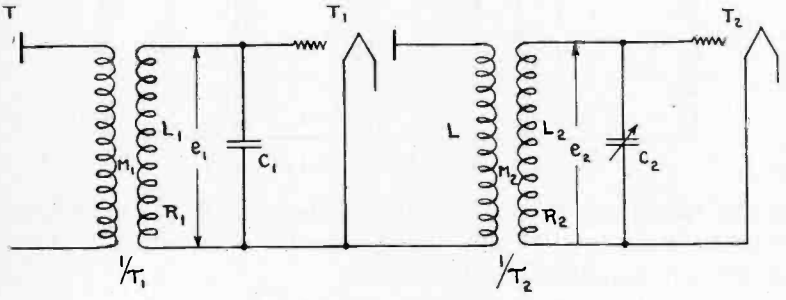

Fig. 1-A—Single-stage tuned input tuned output.

Fig. I-A shows the circuit that will be considered and Fig. I-B as the equivalent transformed circuit. Beatty[2] derived the following equation for A_v of one stage considering regeneration.

$$Av = \frac{e_2}{e_1} = j\,AF \tag{1}$$

where

$$\frac{1}{F} = (1 + j\tan\theta_1)(1 + j\tan\theta_2) + jH \tag{2}$$

$$H = \frac{g_m \omega C_0}{g_1(g_p + g_2)} \tag{3}$$

$$A = \frac{g_m}{g_p + g_e} \tag{4}$$

$$\tan\theta_1 = \frac{\omega(C_1 + C_0) - 1/\omega L_1}{g_1} \tag{5}$$

[2] R. T. Beatty, "The stability of the tuned-grid tuned-plate h-f amplifier," *Experimental Wireless and Wireless Engineer*, 3, January, 1928.

$$\tan \theta_1 = \frac{\omega(C_2+C_0)-1/\omega L_2}{g_2+g_p} \tag{6}$$

$$g_1 = R_1/\omega^2 L_1^2 \tag{7}$$

$$g_2 = R_2/\omega^2 L_2^2. \tag{8}$$

These results are derived for impedance-coupled circuits. To reduce these results to transformer-coupled circuits it is necessary to

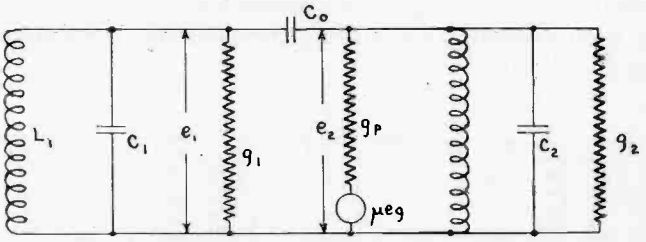

Fig. 1-B—Equivalent circuit of Fig. 1-A.

use the effective-turn ratio τ which is the ratio of the secondary inductance to the mutual inductance. The factor A, which is the non-regenerative amplification, becomes:

$$A = \frac{g_m}{g_p+g_c} \cdot \tau \tag{9}$$

The effect of the resistance of the preceding tube r_p is taken into account by adding a resistance $\omega^2 M_1^2/r_p$ to R_1. The value of g_1 in (7) becomes:

$$g_1 = \frac{R_1+\omega^2 M_1^2/r_p}{\omega^2 L_1^2}. \tag{10}$$

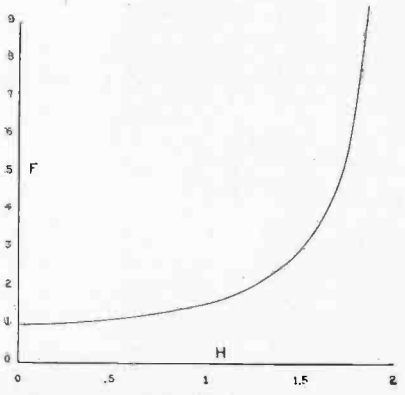

Fig. 2

The vector F is the regeneration factor. Beatty[2] showed that the vector $1/F$ is the distance between H and a parabola, and that the circuit would oscillate when H was 2 or greater. The author[1] showed that mathematically the limit of 2 was correct for one stage. Fig. 2 shows the value of F plotted against the value of H assuming both the input and output circuits of Fig. I-A are tuned for the greatest possible amplification.

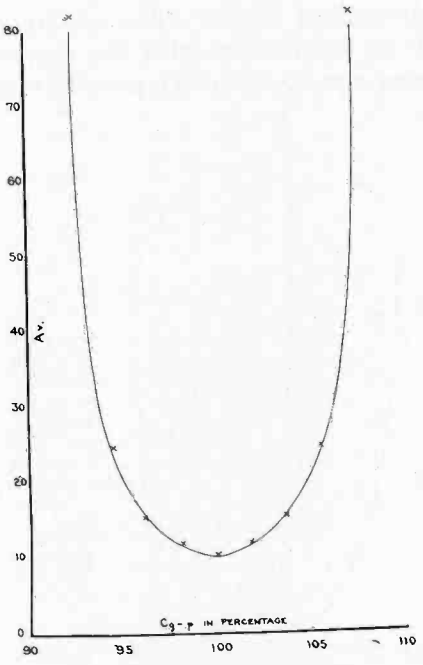

Fig. 3—Voltage amplification vs. percentage of $C_g - p$ in a balanced circuit using a CX-340 tube.

Tube Constants { $g_m = 428 \times 10^{-6}$ mhos; $\mu = 30.8$; $r_p = 72{,}000$ ohms; $C_g - p = 9.9$ $\mu\mu f$

Fig. 3 shows an experimentally determined amplification curve, using a CX-340 tube, obtained by varying the balancing condenser and leaving the grid to plate capacity fixed. This curve has the amplification plotted against balanced percentage of tube capacity. The calculated points are indicated by crosses. The constants of this circuit after transferring the circuit similar to Fig. I-B are given in Table I.

TABLE I

CONSTANTS OF CIRCUIT USED TO MEASURE REGENERATIVE AMPLIFICATION

L_1	L_2	M	G_1	G_2	τ	ω	A	C_0 $\mu\mu f$	H	F
microhenries			micromhos							
240	240	50	8	178	4.8	8.35×10^6	10.36	0	0	1
								0.19	0.455	1.11
								0.38	0.91	1.47
								0.57	1.36	2.39
								0.76	1.82	8.0

There is fairly close agreement between the theoretical and the experimentally determined curves. The assumption that the same amplification will be obtained whether the mutual capacity of the tube or the balancing capacity is varied is justified from the experimental curve.

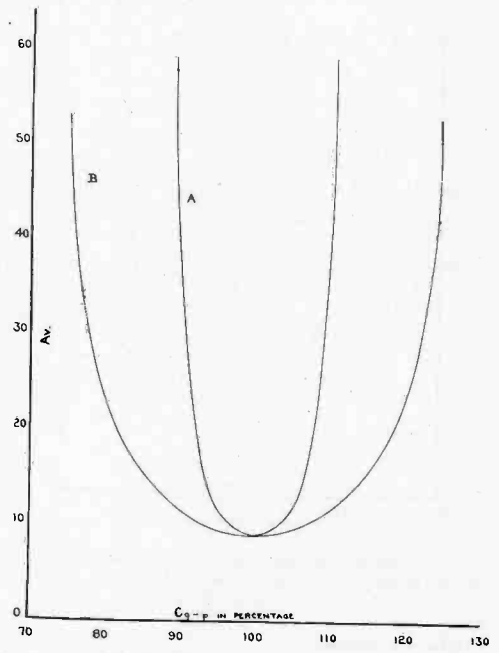

Fig. 4—Theoretical voltage amplification vs. percentage of C_g-p in a balanced circuit.
A—CX-340 tube with C_g-p 8.8 $\mu\mu f$
B—CX-301A tube with C_g-p 8.0 $\mu\mu f$

Fig. 4 shows two calculated amplification curves considering regeneration. These curves were calculated by using average values of the CX-340 type and the CX-301A type tubes. The same secondaries were used in each case and the mutual inductances were calculated to give the same non-regenerative amplification. The circuit constants are given in Table II for each type of tube.

TABLE II

L_1	L_2	M	G_1	G_2	τ	ω	A	C_0 $\mu\mu f$	H	F
microhenries			micromhos							
CONSTANTS FOR CIRCUIT USING CX-340 TUBE										
240	240	42	8.12	252	5.71	9×10^6	9.02	0	0	1
								0.088	0.162	1.02
								0.264	0.486	1.125
								0.440	0.81	1.34
								0.616	1.134	1.79
								0.792	1.458	2.72
								0.968	1.782	6.6
CONSTANTS FOR CIRCUIT USING CX-301A TUBE										
240	240	22	8.57	911	10.9	9×10^6	9.07	0.32	.28	1.043
								0.96	0.84	1.37
								1.44	1.26	2.06
								1.6	1.4	2.48
								2.0	1.75	5.84

Fig. 4 shows how the stability of a balanced amplifier considering the control grid to plate capacity as the variable may be affected by the choice of different types of tubes. It is easily seen that certain types of tubes are preferable to other types provided that it is possible to design the amplifier to give the non-regenerative amplification desired with the type of tubes considered.

GENERAL DISCUSSION

The general case will be discussed only for the case of impedance coupling. The conductance for this case is the same whether considering the plate circuit of one tube or the grid circuit of the succeeding tube. If transformer coupling is used or the input to one stage is an antenna coil, the case may be considered in a manner similar to the preceding analysis in this paper.

The point of most interest is how the curves of Fig. 4 would be affected by the use of n stages instead of one stage. In the paper previously referred to it was shown that the constant H becomes H/n for n stages. This means that if all the tubes used had the same effective C_0, the curves of Fig. 3 would only be $1/n$ as wide for n stages as they would be for one stage.

The curves similar to Fig.4 for n stages could be made the same width as those of Fig. 4 by decreasing the amplification. From the general formula $A_v < \sqrt{2g_m/n\omega C_0}$ it is seen the the limit of stable amplification decreases inversely as the square root of n as n is made larger than unity. The value of H in (3) for n stages becomes

$$H = ng_m\omega C_0/g_1(g_p+g_2) \text{ or } ng_m\omega C_0/g^2. \tag{11}$$

There are two conductances in (11). In order to obtain the same value of H for n stages as for one stage it is necessary to multiply

each conductance by the square root of n. The voltage amplification is g_m/g, so that to have the same width curves for n stages as we have on Fig. 4 it would be necessary to reduce the non-regenerative amplification by $1/\sqrt{n}$.

The results obtained indicate the advisability of considering a new tube factor $\sqrt{g_m/C_0}$ as a comparison of tubes designed to use in high-frequency amplifiers. The higher this factor, the higher the limit of stable amplification will be. The tube with the highest value of $\sqrt{g_m/C_0}$ would be the best one to use in any balanced or neutralized amplifier, as can be seen by writing (11) as

$$H = nA_v^2\omega C_0/g_m. \tag{12}$$

Equation (12) shows that as $\sqrt{g_m/C_0}$ is made larger the value of H for any given value of A_v will decrease so that the width of the regenerative amplification curves would increase, making the amplifier more stable.

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PUSH-PULL PIEZO-ELECTRIC OSCILLATOR CIRCUITS*

By
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Summary—*Comparative tests have been made of five different push-pull piezo-electric oscillator circuits. Two of these circuits use three-element tubes: (1) crystal in four-electrode mounting connected to the grids and anodes, (2) crystal in two-electrode mounting connected to the grids. The other circuits use four-element tubes, (3) screen-grid tubes with the crystal in a four-electrode mounting connected to the control grids and anodes, (4) space-charge-grid tubes, quartz crystal in four-electrode mounting connected to the control grids and anodes, (5) space-charge-grid tubes, crystal in two-electrode mounting connected to the control grids. These circuits have been tested at 90 kc for relative power output and variation of frequency with circuit constants. The type UX-210 tube was used with the circuits (1) and (2) and type UX-865 screen-grid tube with the circuits (3), (4), and (5). The ratios of the power outputs at 90 kc of the circuits (1), (2), (3), (4), and (5) are 10.7, 9.6, 12.9, 1.68 and 1.0, respectively. The power output of circuit (3) at 315 volts with the grid bias through 2-megohm resistors was 0.50 watt at 90 kc. Using the same circuit with 450 volts on the anodes and the grid bias through chokes the power output was 5.20 watts. Considering the low frequency these are reasonable values. The power output of the circuits (4) and (5) is abnormally small, but this may be due to the fact that the UX-865 is not particularly well adapted for use in this type of circuit. The circuits have variations of frequency with circuit constants of the same order of magnitude as has been found with the Pierce oscillator. The circuit of Fig. 3 is particularly adapted to use with crystals at flexural vibration frequencies.*

PUSH-PULL circuits are of course well known; nothing has been published, however, on the characteristics of this type of circuit when used as a piezo-electric oscillator. The present work is a study of various crystal circuits of this type using three- and four-element tubes. The problem was undertaken primarily to determine the desirability of using this type of circuit with quartz crystals at flexural vibration frequencies. For this reason practically all of the observations here recorded were made at frequencies lower than 100 kc.

Fig. 1 shows a push-pull quartz oscillator circuit using two three-element tubes. The crystal Q has a mounting of four electrodes, A, B, C, and D. One pair of electrodes BD is connected to the input of the amplifier, i.e., the grids of the vacuum tubes, and the other pair AC is connected to the output or the anodes of the vacuum tubes. Connected in this manner the crystal can feed back energy from output to input and thus set up sustained oscillations in the circuit.

* Dewey decimal classification: R214.

These conditions can be satisfied for any mode of vibration of the crystal, so the output circuit LC is tuned to the mode of vibration we wish to excite. In this work it has been found convenient to use two coils of the same size in series instead of a single center tapped coil. The inductance Ch is a choke coil to exclude oscillatory currents from the anode potential supply branch of the circuit. The power output is very much increased if the grid circuit resistors R_1 and R_2 are replaced by choke coils. This circuit belongs to the general type of quartz oscillator first described by Cady[1] where the crystal functions as a coupling device between the input and output circuits of an amplifier. Difficulty has been experienced with this circuit (Fig. 1) and with the others of this type here described because of sparking between the crystal and the electrodes of its mounting. It can be entirely

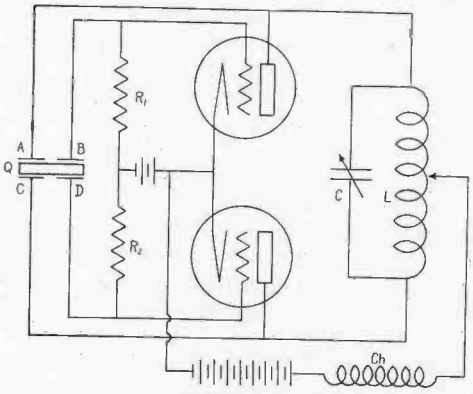

Fig. 1—Push-pull piezo-electric oscillator with three-element tubes using feedback through the crystal.

eliminated by mounting the crystal in an evacuated chamber with a vacuum of approximately 0.01 mm, when the residual gas is ordinary air. At low anode potentials of 150 volts or thereabouts the sparking is not usually noticeable, even though the crystal is not mounted in vacuum.

In the circuit of Fig. 2, two three-element tubes are also used. The crystal Q has a mounting consisting of two electrodes A and B, which are connected to the grids or input of the amplifying system. This circuit belongs to the general type of quartz oscillator first described by Pierce[2] where the crystal functions as an inductive or capacitive reactance. Oscillations are sustained in this type of circuit by energy feedback through the interelectrode capacity of the vacuum tubes.

[1] W. G. Cady, Proc. I. R. E., 10, 83; April, 1922.
[2] G. W. Pierce, *Proc.* Amer. Acad., 59, 81, 1923.

In this circuit (Fig. 2) it is the grid-anode interelectrode capacity of the tubes. Higher anode potentials can be used with this type of circuit than with the circuit of Fig. 1 without encountering sparking between the crystal and the electrodes of its mounting. Tests indicate that in all push-pull crystal circuits the danger of breaking the crystal at a given anode potential is very much greater than when using a Pierce circuit with a single tube. This may seem curious when it is found that the current in the crystal is less in the push-pull circuit than in the Pierce circuit. It is obvious that with any given type of crystal-oscillator circuit the crystal vibrates at some particular point on the resonance curve. This point may be on either side of the peak of the curve depending on the circuit. So then when the crystal is transferred from one type of circuit to another it may be expected

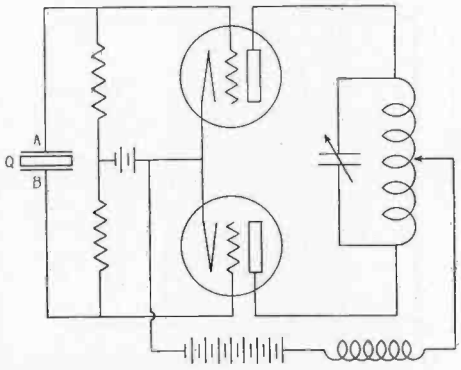

Fig. 2—Push-pull piezo-electric oscillator with three-element tubes using feedback through the tubes.

to vibrate at a slightly different frequency. This means too that there is a slightly different phase relationship between voltage and current. Quite different currents through the crystal may be expected in circuits of different types even though the power output is the same. The current through the crystal alone is not a measure of the stress in it. Stress depends not only on current but on nearness to the resonance frequency. This probably explains why the crystals break more easily in push-pull circuits.

In the circuit of Fig. 3 two screen-grid four-element tubes are used. The crystal has a four-electrode mounting and acts as a coupling device between the input and output circuits. This circuit operates in a similar manner to the circuit of Fig. 1. At low frequencies (100 kc and lower) it is a great advantage to use the screen-grid tube. It is much easier to make a crystal oscillate when using this type of tube

at these frequencies, and the power output is usually much larger than with a three-element tube. The advantage is largely due to the high amplification factor of the screen-grid tube.

It is not unusual to find that a crystal oscillates at either one of two frequencies very close together for a given mode of vibration when using the type of circuit shown in Figs. 1 and 3. These twin oscillation frequencies, which have been described elsewhere,[3] simply indicate that the conditions for oscillation in the circuit are satisfied at two points on the same resonance curve of the crystal. At one of these points the crystal is acting as a coupling device between the input and output of the amplifier, and at the other it assumes the role of a reactance connected to the input of the amplifier. The former case corresponds to the conditions in the Cady type of oscillator, and the latter

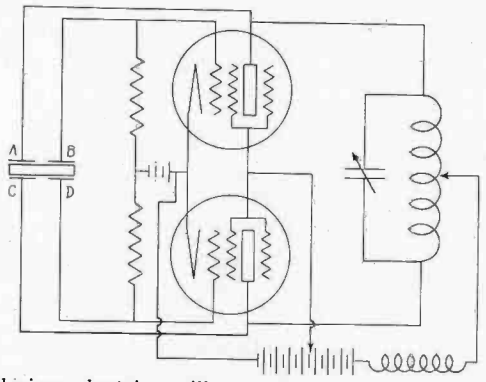

Fig. 3—Push-pull piezo-electric oscillator with screen-grid tubes, using feedback through the crystal.

to the Pierce type. When screen-grid tubes are used as in Fig. 3 the latter type of the twin oscillation frequencies can be eliminated if the pairs of electrodes AC and BD are sufficiently far apart. One or two cm is usually a great enough distance. When the input and output electrodes of the crystal mounting are close together, a capacity is introduced between the control grids and anodes of the vacuum tubes which transmits sufficient energy from output to input to sustain oscillations at the second oscillation frequency. The screen-grid push-pull circuit (Fig. 3) is particularly recommended for use with flexural vibrations. Care must be exercised, however, when using anode potentials of 400 volts or higher. On two or three occasions while using the flexural vibration mounting[4] the circuit was tuned for considerably

[3] J. R. Harrison, PROC. I. R. E., **16**, 1455; November, 1928.
[4] J. R. Harrison, PROC. I. R. E., **15**, 1040; December, 1927.

higher frequency than for flexural vibrations and the crystal was shattered. The frequency at which the shattering occurred, according to the condenser setting, was in the neighborhood of the frequency for longitudinal vibrations due to the transverse effect.

Tests indicate that the variation of frequency of oscillation of these push-pull oscillator circuits with circuit constants such as anode and

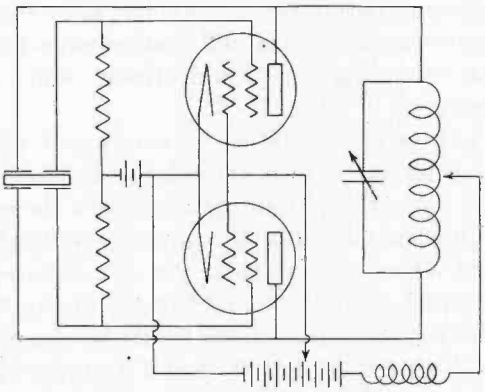

Fig. 4—Push-pull piezo-electric oscillator with space-charge-grid tubes using feedback through the crystal.

filament potentials are of the same order of magnitude as those found with the Pierce oscillator circuit. The power output from these circuits is usually about one and one half times that obtained when

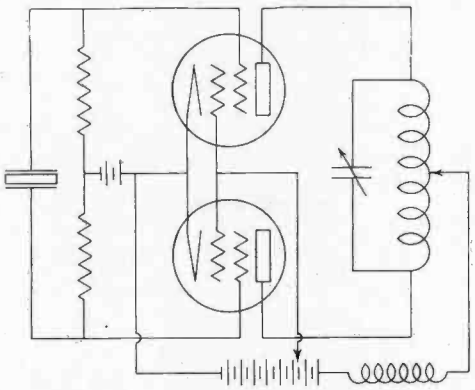

Fig. 5—Push-pull piezo-electric oscillator with space-charge-grid tubes using feedback through the tubes.

using the same crystal in a circuit using but one vacuum tube of the same type. As with single tube circuits, the power output obtainable diminishes toward the lower frequencies. For example at 1100 kc

it is not difficult to obtain a power output of 20 watts with a push-pull circuit, but at 50 kc 5 watts was approximately the maximum power obtained. These results represent averages from several crystals.

Fig. 4 illustrates another push-pull oscillator circuit using four-element tubes. Here the vacuum tubes function as space-charge-grid devices. The crystal has a four-electrode mounting which is coupled between the input and output of the amplifier as in Figs. 1 and 3.

Fig. 5 illustrates another push-pull space-charge-grid tube circuit. Here the crystal mounting has two electrodes which are connected to the control grids.

The power output was found to be very small with the circuits of Figs. 4 and 5 when the UX865 four-electrode tube was used. The power was about one tenth of that obtained with the circuit of Fig. 3 using the same tubes and crystals and approximately the same circuit constants. The UX865 is designed for use as a screen-grid tube and, therefore, is probably not well adapted to use in this type of circuit. The ratios of the power outputs at 90 kc of the circuits (1), (2), (3), (4), and (5) are 10.7, 9.6, 12.9, 1.68, and 1.0, respectively, using the types of tubes mentioned.

The author is very grateful to Professor Cady for the facilities and assistance placed at his disposal in doing this work.

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LONG-WAVE RADIO RECEIVING MEASUREMENTS AT THE BUREAU OF STANDARDS IN 1928*

By
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Summary—*This paper gives monthly averages of daylight signal intensity at Washington for 1928 from a number of European and American low-frequency stations. The annual field intensity averages of both European and nearby American stations were found slightly lower than those of 1927, while atmospheric disturbances varied little from the year before.*

THE monthly average daylight signal intensities of stations at various distances, measured in Washington in 1928, are given in the following tables. The tables also contain the monthly average intensity of atmospheric disturbances (static).[1]

TABLE I

Transmission Data, 1928

	Frequency f(kc)	Wave length λ(m)	Antenna current I(amperes)	Effective height h(m)	Distance d(km)
LY,* Bordeaux	15.9	18,900	535	180	6160
FU, Ste. Assise, Paris	15.0	20.000	475	180	6200
FT,* Ste. Assise, Paris	20.8	14,400	344	180	6200
AGW,* Nauen, Berlin	16.5	18,100	414	170	6650
AGS,* Nauen, Berlin	23.4	12,800	389	130	6650
GBR,* Rugby	16.1	18,600	685°	185	5930
GBL,* Leafield	24.4	12,300	210	75	5900
GLC, Carnarvon	31.6	9,500	—	—	5840
KET,* Bolinas, San Francisco	22.9	13,100	600	51	3920
IRB, Rome	20.8	14,400	—	—	7160
NAU,* Cayey	33.8	8,870	104	120	2490
NPL,* San Diego	30.0	10,000	89	120	3700
PCG, Kootwijk	16.8	17,800	—	—	6100

* Daily antenna currents reported. Other antenna currents more or less uncertain.
° Six months average only.

The signals marked A.M. in the tables were received between 10 and 11 A.M. (E.S.T.) with daylight along the whole path of transmission, except for a short time in winter in the case of the two stations AGS and AGW at Nauen near Berlin when the sun sets slightly before 10 A.M. (E.S.T.). The signals marked P.M. were received between 3 and 4 o'clock in the afternoon with full daylight transmission in the case of southern and western stations and transmission partly in darkness and partly in daylight for European stations excepting Rugby

* Dewey decimal classification: R113. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.
[1] For method of measurement see Proc. I. R. E., 12, 529; October, 1924.

(GBR) and Leafield (GBL), whose signal paths lie entirely in daylight in midsummer.

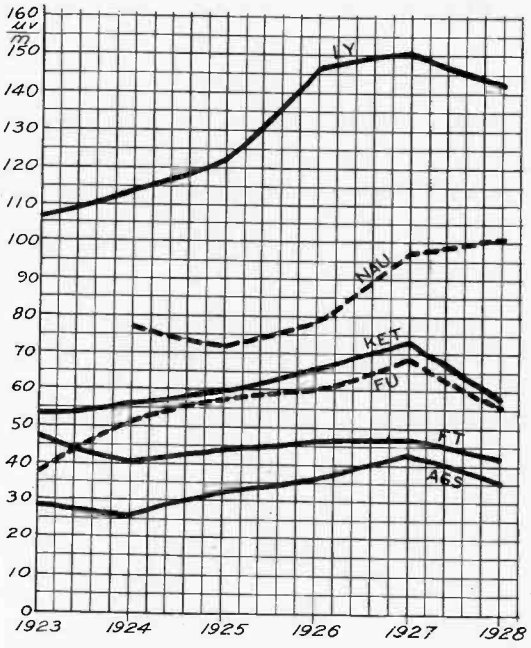

Fig. 1—Annual average signal, 10 A.M.

TABLE II

AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR LAFAYETTE (LY), RUGBY (GBR), STE. ASSISE (FU), NAUEN (AGW), AND KOOTWIJK (PCG), IN MICROVOLTS PER METER

	A.M.						P.M.					
1928	LY	GBR	FU	AGW	PCG	Dist.	LY	GBR	FU	AGW	PCG	Dist.
Jan.	127	138	49	50	49	26	206	200	98	62	67	27
Feb.	119	—	43	49	49	29	164	178	83	65	67	37
Mar.	130	—	55	50	54	35	154	—	69	61	62	54
Apr.	140	—	—	54	58	44	113	147	52	46	48	59
May	173	—	—	57	61	47	113	—	—	39	42	83
June	143	—	—	57	61	57	85	—	—	35	37	123
July	134	148	57	59	62	45	74	83	—	37	39	140
Aug.	165	150	—	45	62	44	78	—	—	26	—	320
Sept.	166	206	—	65	67	35	123	140	—	50	50	74
Oct.	141	165	—	51	54	43	162	213	—	57	59	53
Nov.	97	—	—	45	49	31	174	199	87	66	69	36
Dec.	167	180	—	72	66	29	251	272	119	95	101	30
Av.	142	164	51	55	58	39	141	179	85	53	58	86

The figures show the annual changes in signal strength and atmospheric disturbances since 1923, the monthly distribution of atmospherics for 1927 and 1928, and the variations in signal strength of Bordeaux (LY) as measured at Meudon (Paris) and in Washington.

The annual field-intensity averages of European stations for the

year 1928 were slightly but consistently lower than those of 1927. This was true for the monthly averages as well, with but very few exceptions, for all months preceding December. In December there was a decided increase in field-intensity values for all European stations.

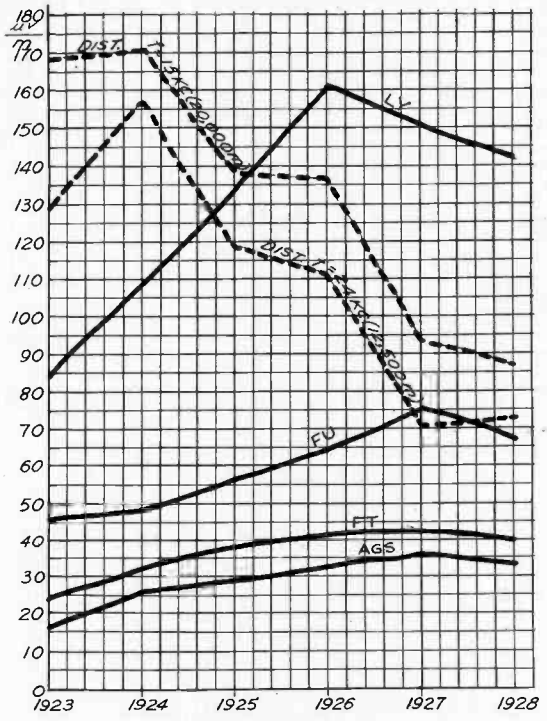

Fig. 2—Annual average signal and atmospheric disturbances, 3 P.M.

The averages were well above those of December, 1927, and were equal to and, in the case of some stations, exceeding those of 1926. This increase continued until March, 1929, but since March there has been a decrease in intensity.

A decrease in the annual average signal strength was apparent also in the measurements on nearby American long-wave stations. The values for the two stations, New Brunswick, N. J. (WII) and Rocky Point, L. I., (WSS), which were measured throughout the two years, were from 10 to 20 per cent lower than in 1927.

The atmospheric disturbances in 1928 varied little in intensity from those of the year before. At a wavelength of 20,000 m the average was somewhat lower, while at 12,500 m it was slightly higher than in 1927. The greatest monthly intensity was reached in August. In 1927 the highest monthly average occurred in July.

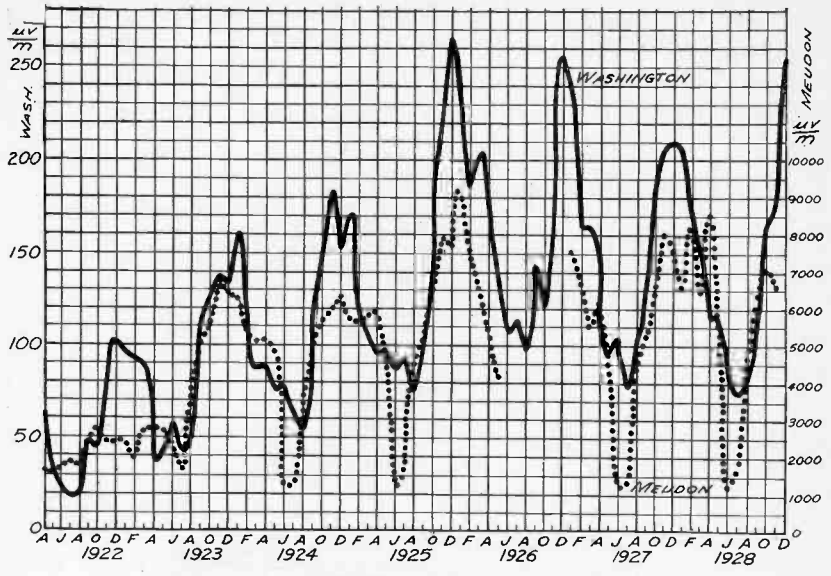

Fig. 3—Lafayette (LY) monthly average signal at Washington and Meudon, 3 P.M.

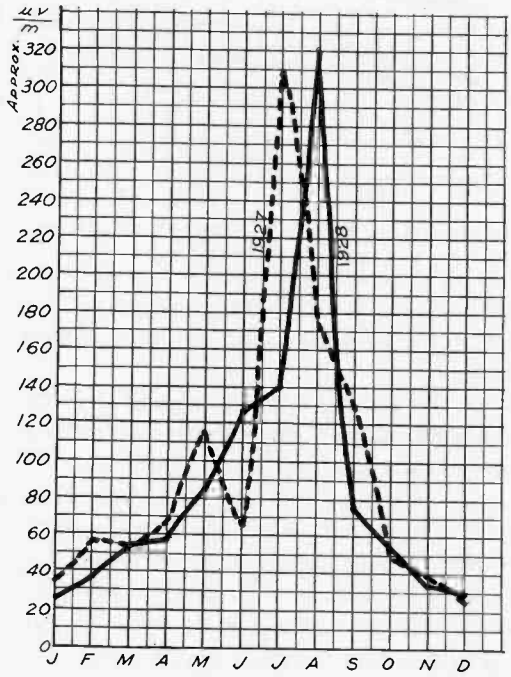

Fig. 4—Monthly average atmospheric disturbances (20,000 m), 1927 and 1928.

TABLE III

AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR ROME (IRB), STE. ASSISE (FT) NAUEN (AGS), BOLINAS (KET), LEAFIELD (GBL), AND CARNARVON (GLC), IN MICROVOLTS PER METER

	A.M.							P.M.						
1928	IRB	FT	AGS	KET	GBL	GLC	Dist.	IRB	FT	AGS	KET	GBL	GLC	Dist.
Jan.	45	36	26	57	13	11	19	71	51	42	61	11	14	23
Feb.	47	39	27	60	14	10	21	60	49	39	68	16	13	28
Mar.	47	40	31	58	38	11	26	53	46	36	64	14	10	42
Apr.	48	40	36	61	16	11	34	40	35	29	54	13	8	45
May	52	40	35	60	15	14	36	35	23	21	40	—	—	68
June	55	44	36	54	—	15	49	34	25	21	39	—	—	110
July	61	48	41	61	—	18	38	32	27	23	39	—	—	120
Aug.	56	44	35	44	—	—	36	—	28	25	—	—	—	280
Sept.	66	46	49	65	—	22	28	47	31	30	47	—	—	61
Oct.	53	—	42	60	—	18	34	53	—	39	51	—	19	48
Nov.	41	—	28	41	—	15	24	66	56	46	65	—	22	31
Dec.	54	—	40	66	—	15	23	84	69	59	86	—	30	25
Av.	52	42	35	57	—	15	31	52	40	34	56	—	17	73

TABLE IV

AVERAGE SIGNAL INTENSITY AND ATMOSPHERIC DISTURBANCES FOR CAYEY (NAU), AND SAN DIEGO (NPL), IN MICROVOLTS PER METER

	A.M.			P.M.		
1928	NAU	NPL	Dist.	NAU	NPL	Dist.
Jan.	111	54	12	69	72	14
Feb.	83	58	13	60	59	17
Mar.	116	72	16	59	69	30
Apr.	77	84	21	65	61	32
May	—	—	21	73	91	47
June	—	—	42	—	—	84
July	84	86	27	48	63	84
Aug.	127	180	18	90	—	22
Sept.	109	116	17	67	—	40
Oct.	—	—	—	—	—	—
Nov.	—	—	—	—	—	—
Dec.	—	—	—	—	—	—
Av.	101	93	21	66	69	41

TABLE V

AVERAGE SIGNAL INTENSITY FOR NEW BRUNSWICK, N. J. (WII AND WRT), TUCKERTON, N. J. (WCI AND WGG), ROCKY POINT, L. I. (WSS), AND MARION, MASS. (WSO), IN MILLIVOLTS PER METER

	A.M.						P.M.					
1928	WII	WCI	WGG	WSS	WSO	WRT	WII	WCI	WGG	WSS	WSO	WRT
Jan.	3.7	—	—	3.4	—	3.7	3.5	—	—	3.4	—	3.6
Feb.	3.2	—	—	3.1	—	3.1	3.2	—	—	3.0	—	3.2
Mar.	2.9	—	—	2.8	—	3.0	2.9	—	—	2.9	—	2.8
Apr.	2.9	—	2.8	2.9	—	3.0	2.9	—	2.6	2.7	—	2.9
May	2.8	—	3.2	2.8	1.1	2.9	2.7	—	2.8	2.8	—	2.8
June	2.2	2.9	—	2.2	1.0	2.4	2.4	2.8	—	2.1	—	2.3
July	2.0	2.7	—	2.0	1.1	2.0	2.1	2.8	—	2.0	0.9	2.1
Aug.	1.8	2.9	—	1.8	1.0	1.9	1.8	3.0	—	1.7	0.9	1.8
Sept.	1.9	—	2.3	2.0	1.1	2.0	1.8	2.9	2.3	1.9	0.9	1.9
Oct.	2.5	3.2	3.1	2.1	1.2	2.6	2.6	3.5	3.1	2.4	1.2	2.9
Nov.	2.5	3.3	2.6	2.2	0.9	2.6	2.9	3.6	3.1	2.5	1.2	2.9
Dec.	2.7	3.7	3.1	2.5	1.1	2.9	2.9	3.8	3.5	2.5	1.2	2.9
Av.	2.6	3.1	2.9	2.5	1.1	2.7	2.6	3.2	2.9	2.5	1.1	2.7

Mimeographed copies of the daily observations of signal intensities and of strength of atmospherics are available for distribution to those interested.

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MULTIPLE SIGNALS IN SHORT-WAVE TRANSMISSION*

By
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Summary—*This paper presents an analysis of the facsimile records obtained recently in the transmissions between New York, U. S. A., and Somerton, England. Since the speed of the scanning spot in the facsimile apparatus is accurately known, these records permit the measurement of the time intervals between the various signals which produce the distortion in the received record. Thus the facsimile apparatus can be used as an oscillograph for Kennelly-Heaviside layer measurements after the method employed by Breit and Tuve and others.*

The results of the analysis confirm, in general, the results of other experimenters and extend them in the direction of giving information as to the angle within which the useful radiation is confined at the transmitter. A knowledge of this angle is then shown to yield important information on the distortion to be expected on different wavelengths. A detailed summary of the results is included at the end of the paper.

Introduction

THEORIES of short-wave transmission depend in the main on pre-knowledge of the Heaviside layer; and on the other hand this pre-knowledge must be based on some theory of short-wave ray transmission, for the Heaviside layer can only be probed by means of short wireless waves, and the interpretation of the results involves the transmission theory. The methods used for probing involve the reception of more than one ray, generally a direct ray over the surface of the earth and an indirect ray which has travelled up to the Heaviside layer and back. Either the difference in time of arrival of short groups is measured or a sustained signal is sent with a varying frequency, and the variations of interference are made to give the requisite information. Information may also be obtained by observing the directions of the incoming waves. The first method has been extensively used in America, and the second by Appleton in England. The first method has been thoroughly discussed, on the assumption that the wave follows a ray path determined by the ionic density in the Heaviside layer.

On the assumption that the gradient of ionic density is everywhere vertical, the difference in time of arrival of the direct signal and the reflected signal gives at once the angle of transmission and the height of the apex B of the ray, i.e., the equivalent height of the layer. (See Fig. 7.)

*Dewey decimal classification: R113.6.

The method, however, fails for short-distance transmission on sufficiently short waves where the density of the layer is not sufficient to bend the rays down. In fact, the method fails where the receiver is within the skip distance.

In recent tests by Kenrick and Jen[1] the experiments were successful on a 67-m wave, but nothing was received on a 33-m wave, suggesting that the latter was too short a wave. In order to get results on shorter waves than this, experiments must be made outside the skip where the time between the direct and echo signals can be made to yield very definite information. An opportunity for examining such a case on a 22-m wave was afforded by the facsimile records obtained recently in the transmissions between New York and Somerton.

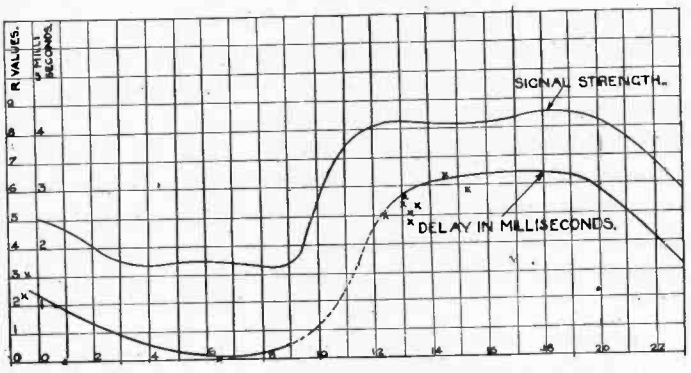


Fig. 1—Echo duration (October-November, 1928) and signal strength. (Station WAJ, 13480 kc.)

The interpretation of the results is fundamentally the same as the above with the proviso that the rays are more nearly horizontal than vertical in such conditions. For the purpose of the analysis of the results, the facsimile apparatus is considered in the nature of an oscillograph. The signals made by the transmitter are in general of sufficiently short duration not to overlap with the echoes. In fact the arrangement is essentially similar to the type of apparatus used in the experiments of Breit and Tuve and other experimenters in America; a faithful record of each signal made at the transmitter and modified in transmission is made at the receiver. For the present purpose it is hardly necessary to enter into details of the apparatus, and it is sufficient to state that practically perfect reproduction is obtained over short distances where the transmission distortions are not present.

[1]Proc. I. R. E., 17, 711; April, 1929.

Short Echoes

A preliminary analysis of short echoes (3 or 4 millisec.) exhibited by the facsimile records taken on the circuit between New York and Somerton on 13480 kc or 22.255-m wave during the period August,

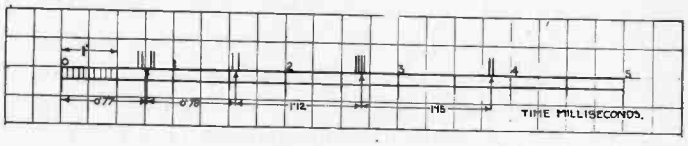


Fig. 2—Echoes.

1928, to January, 1929, has brought to light facts which may be of considerable practical importance in facsimile working. They are also of great significance in constructing a working model of the Heaviside layer and giving a rational explanation of the bewildering variety of results obtained in short-wave interception.

In a preliminary survey something like 20 or 30 cases of the echo signals shown on the facsimile photographs have been measured up, and these are typical selections from the large amount of material accumulated. A fairly close examination of the main bulk of the material suggests that very little will be added but repetitions by measuring it all.

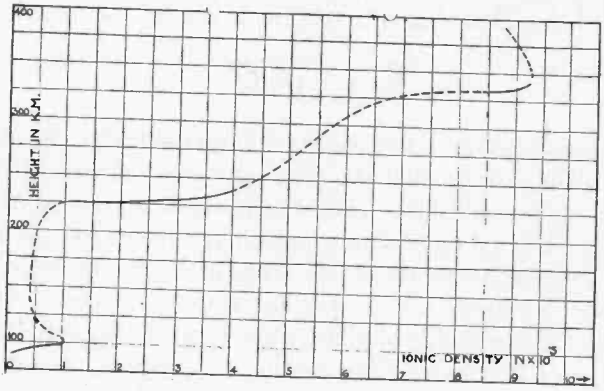


Fig. 3—The Heaviside layer.

Anyone who knows the actual mechanism of the facsimile gear will realize that it gives an excellent record of the mutilation of signals in their passage from the transmitter to receiver, a comparison of the transmitted and received picture immediately showing up the signal mutilation.

Examination of the records shows that if one short signal (<0.5 millisec. duration) is transmitted this may be reproduced as 1, 2, 3, 4, 5, or even 6 separate signals at the receiver. Thus if a single line (drawn perpendicular to the direction of scan of the light spot) is transmitted, it is reproduced as a group of 2, 3, 4, or 5 lines closely spaced.

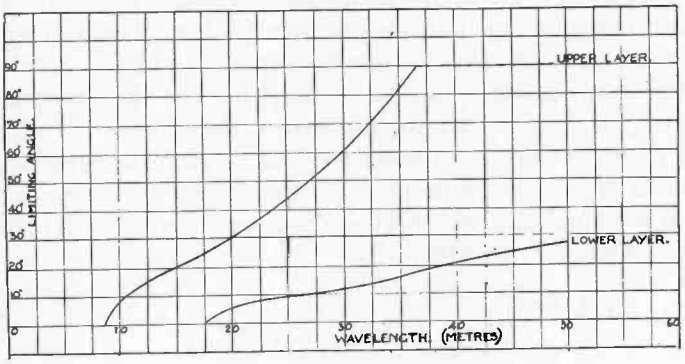


Fig. 4—Limiting angle for transmission.

We may call the first signal that arrives the main signal and the latter short echoes of it. If the distance between the lines on the received photograph is measured it is possible to calculate the time intervals when the speed of the scanning spot is known.

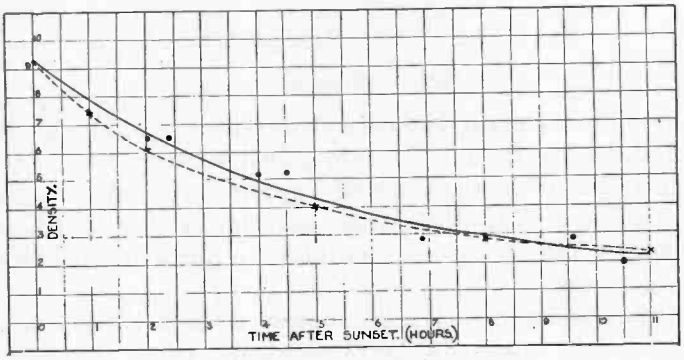


Fig. 5—Ionic recombination.

The speed of the scanning spot is determined by the frequency of the controlling fork and is accurately known.

It is therefore possible to make accurate measurements of the time intervals between the main signal and the various echoes. With a

300-cycle fork the scanning speed is 30 min. per sec. and clearly separates short signals (of the order of 1/5000 sec.) with time intervals less than a millisecond.

Most of the pictures were run off near the middle of the day (when signals were strongest) and the information on night transmission is meager.

It appears that during the hours 1200 to about 1500 echoes up to the number of three or four are prevalent in nearly every case, with delays up to 3.8 millisec. and in one case up to 5.3 millisec.

In the evening echoes are still prevalent, but the extreme delay (between first and last) seems to decrease throughout the night and to be a minimum about sunrise here and to increase rapidly as the sun rises at New York, tending to its maximum value when the sun is on the meridian half way between Somerton and New York. (See samples in Figs. 8, 9, and 10.)

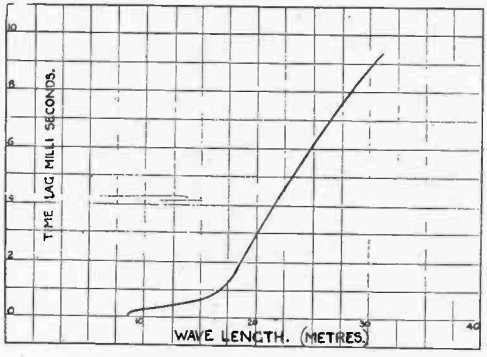


Fig. 6—Observed curve.

The results are plotted on curve 1 showing the total echo duration as a function of the local time for the period between October 15th and November 7th. It shows a diurnal variation very similar to the signal strength curve of WAJ, the station used during this period, showing that when signals are strong multiples are prevalent and disappear as the signal weakens.

The time between each echo appears to be between 0.7 and 1.2 millisec. and the later ones are more widely spaced than the earlier ones (of any given group).

The times of individual echoes are rather irregular, but on particular occasions we have found a very regular arrangement repeated again and again within the period of a minute or so.

These are represented in Fig. 2 and may be taken as a representative set of echoes.

The maximum delay (between the first and last signal) may be used to give very interesting data concerning the Heaviside layer which can be used to determine the behavior as regards facsimile echoes on other wavelengths. This use depends on the following relation derived from the ray theory.

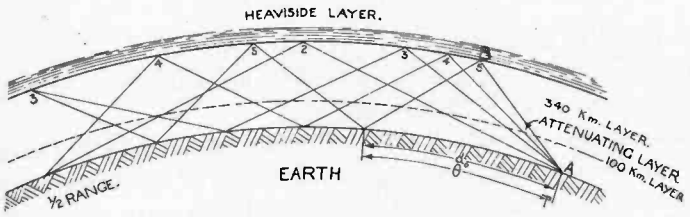


Fig. 7—Theoretical recombination curve.

If the gradient in the layer is purely vertical (as we may assume is the case when conditions are nearly uniform between transmitter and receiver) and if the ray does not depart from the earth's surface more than a small fraction of the earth's radius, then the time of travel of any one of the echo signals, say the nth, is

$$\tau_n = \frac{d}{c}\,\frac{1}{\cos \theta n}$$

the echo time is $\tau_n - \tau_1$

$$\frac{d}{c}\left[\frac{1}{\cos \theta_n} - \frac{1}{\cos \theta_1}\right] \tau_n - \tau_1$$

since d, c, and $\tau_n - \tau_1$ are known

$$\frac{1}{\cos \theta_n} - \frac{1}{\cos \theta}$$

is given.

This gives a relation between θ_1 and θ_n, but not θ_1 and θ_n separately.

The assumption made here is that θ_1 is very small so that $1/\cos \theta_1$ is practically unity. This can be justified in the present case from our knowledge of the Heaviside layer. Thus we know from various experimenters, notably Appleton, that there is a maximum density of 10^5 electrons per cu. cm at the height of very closely 100 km. See Fig. 3.

On a 22-m wave all rays with initial angles of elevation less than 9 deg. are bent down by this layer, so that if we assume that the first signal is produced by rays which are confined to regions below this first layer

$$\frac{1}{\cos\theta_1} < \frac{1}{\cos 9\ \text{deg.}}$$

i.e.,

$$\frac{1}{0.9877} = 1.0123.$$

The effect of assuming $\theta_1 = 0$ gives an error in timing of less than 0.2 millisec., which amounts to an error of less than 5 per cent in cases of the extreme echoes of about 4 millisec.

The assumption enables us to calculate cos θ_n, and if n is the last echo, it gives the maximum angle of elevation of the transmitted ray. Presumably longer echoes and higher angle rays are not present because such high-angle rays would penetrate the layer and not be returned to earth. Values of θ_n determined in this manner are given below.

Date	G.M.T.	θ_n	N. h = 240 km	N. h = 340 km
Oct. 20th	1517	30 deg. 57 min.	7.80×10^5	8.40×10^5
" 21st	2315	20 " 16 "	4.5×10^5	5.2×10^5
" 21st	1302	29 " 46 "	7.40×10^5	8.05×10^5
"		30 " 07 "	7.60×10^5	8.15×10^5
Nov. 12th	1321	28 " 35 "	7.05×10^5	7.70×10^5
" 7th	1328	28 " 35 "	7.05×10^5	7.70×10^5
		28 " 30 "	7.0×10^5	7.65×10^5
	1536	34 " 36 "	9.1×10^5	9.8×10^5
		34 " 23 "	9.0×10^5	9.6×10^5
Nov. 2nd	1435	31 " 47 "	7.8×10^5	8.8×10^5
Mean Value		30 " 47 "	7.75×10^5	8.43×10^5

The maximum value o θ_n is therefore less than 35 deg. and the mean 30 deg. 47 min.

We may therefore state that on 22 m over the Somerton—New York circuit the *ray angles of the transmitted rays are less than 35 deg. and usually less than 31 deg.*

The higher angle rays are usually weaker than the others, and it follows that the *main energy is transmitted along rays* < 20 deg. elevation.

This is a complete confirmation of our previous results obtained with the cardioid receiver, i.e., that long-distance communication is effected with relatively low-angle rays.

These results determine the ray angles with immensely greater accuracy than any balanced aerial system is likely to do.

These ray angles can now be used to calculate the maximum density (at the apex of the rays) from the relation

$$\cos\theta=\frac{R+h}{R}\cdot\frac{\mu}{\mu_0}\cdot\frac{\mu}{\mu_0}=\sqrt{1-\frac{Ne^2c^2}{\pi mn^2}}\quad\text{or}\quad\sqrt{1-\frac{{n_0}^2}{n^2}}$$

where h is the height of the ray above the earth at its apex. when $h/R=x$ is small and θ is small

$$\frac{{n_0}^2}{n^2}=\frac{Ne^2c^2}{\pi mn^2}=\sin^2\theta+2x$$

from which N can be determined.

This contains the unknown quantity x, the ratio of the height of the layer to the earth's radius, so that N cannot be *accurately* determined unless x is known. If θ is large, however, so that $\sin\theta\gg 2x$, for even the

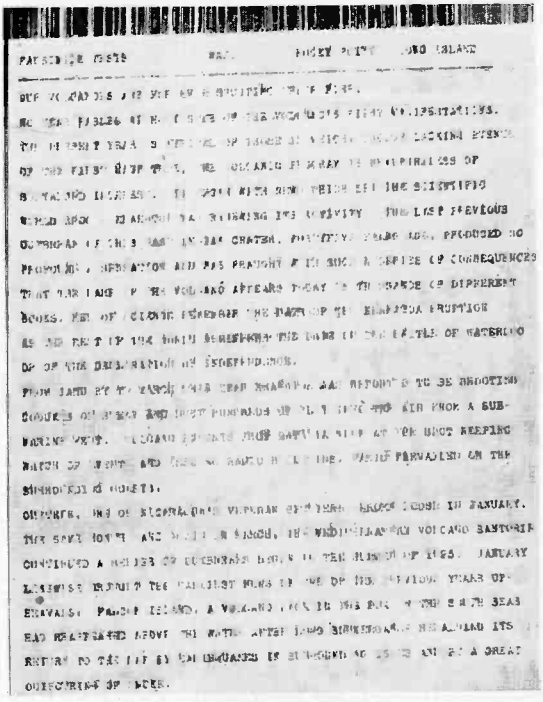
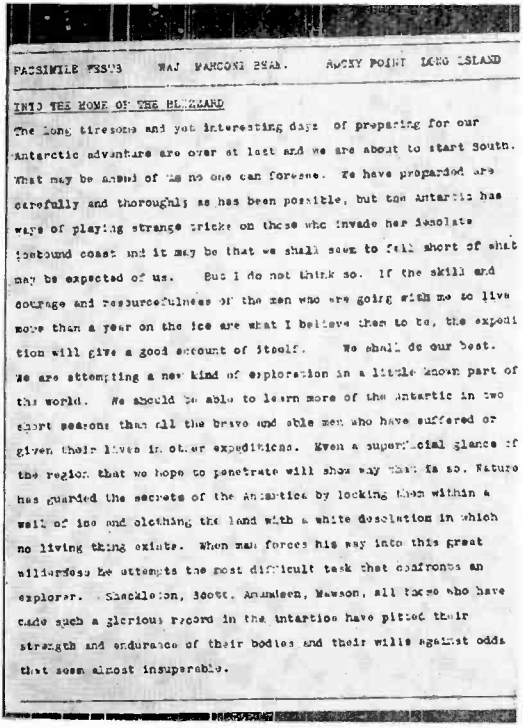


Fig. 8—Specimen taken October 21, 1928 at 2335 G. M. T., Somerton. Speed, 300 cycles. Lighter limit. Many drop outs. Showing decreasing echo time at midnight. High-angle echo tending to drop out. About 1.48 millisecond delay.

maximum possible values of h, the effect of x on N in inappreciable. Unfortunately in this case $\sin^2\theta$ is of the order 0.25 and $2x$ may be 0.08 so that an error of 30 per cent may be made, but the actual error will

probably be much less since x can be estimated within fairly narrow limits from the other observations and the error in $2x$ is not likely to be greater than 0.03, giving a percentage error in N of about 12 per cent.

Two sets of N values are given, one with h assumed to be 226 km. (Derived from measurements made by Appleton,[2] and Breit, Tuve, and Dahl[3] on 100-m and 75-m waves, respectively. (Kenrick and Jen)[1].



FACSIMILE TESTS WAJ MARCONI BEAM. ROCKY POINT LONG ISLAND

INTO THE HOME OF THE BLIZZARD

The long tiresome and yet interesting days of preparing for our Antarctic adventure are over at last and we are about to start South. What may be ahead of us no one can foresee. We have prepared are carefully and thoroughly as has been possible, but the Antarctic has ways of playing strange tricks on those who invade her desolate icebound coast and it may be that we shall seem to fall short of what may be expected of us. But I do not think so. If the skill and courage and resourcefulness of the men who are going with me to live more than a year on the ice are what I believe them to be, the expedition will give a good account of itself. We shall do our best. We are attempting a new kind of exploration in a little known part of the world. We should be able to learn more of the Antartic in two short seasons than all the brave and able men who have suffered or given their lives in other expeditions. Even a superficial glance of the region that we hope to penetrate will show why that is so. Nature has guarded the secrets of the Antartica by locking them within a wall of ice and clothing the land with a white desolation in which no living thing exists. When man forces his way into this great wilderness he attempts the most difficult task that confronts an explorer. Shackleton, Scott, Amundsen, Mawson, all those who have made such a glorious record in the Antartica have pitted their strength and endurance of their bodies and their wills against odds that seem almost insuperable.

Fig. 9—Specimen taken October 22, 1928 at 0620 G. M. T., Somerton. Speed, 150 cycles. Showing decreasing echo time at early morning. High-angle echo tending to drop out.

The other set is with $h=340$ km, this value being given by the measurement of the echo times (also by Kenrick and Jen.)[1]

N appears to be of the order 8 to 9×10^5, i.e., nearly 10 times the maximum value of N in the 100-km layer.

At this point it is necessary to sketch briefly our knowledge of the Heaviside layer as determined by other experiments.

[2] *Nature*, p. 445, March 23, 1929.
[3] Proc. I. R. E. 16, 1236; September, 1928.

Interference experiments made by Appleton and Hollingworth and signal-strength measurements made by the author on long waves show that the electron density increases rapidly above 75 km and rises to a maximum of 10^5 at 100 km (in daylight.)

Recent experiments made by Appleton on 100-m wave and described in *Nature*[2] show that the measured effective height of the layer (by interference methods) jumps discontinuously at irregular times from 100 to 226 km, which may be interpreted on the assumption that the lower layer is so nearly only just sufficient to reflect the 100-m wave that a very slight diminution in N from time to time exposes a higher layer at 226 km. The density between $N=10^5$ at 100 km and $N=10^5$ at 226 km is then everywhere less than this value.

Measurements made on 75 m and 67 m show that in the daytime the signal is reflected at an effective height of 226 km, and that the density there is 2.4×10^5 or greater. We may therefore sketch in the average day density as in Fig. 3, which is derived from the average of the data. There is a fairly well-defined layer up to $N=10^5$ at 90 to 100 km, another at least 2.4×10^5 at 226 km.

Finally at nighttime Kenrick and Jen[1] results seem to show another layer exposed by the recombination of ions below about 344 km height. From these data it seems reasonable to suppose that the 22-m echo rays are reflected between 240- and 340-km heights, and the maximum densities in the layer are calculated for these two heights and give the probable limits. The mean densities corresponding to the two heights are 7.75 and 8.43, the latter probably more nearly correct.

Maximum Density in the Layer

The fact that there is a certain maximum delay implies a certain maximum angle of transmission, approximately 35 deg. It is well known that corresponding to a certain maximum density in the layer there is a limit to the angle of projection of the ray if this ray is to return to earth again. It seems certain that higher angles are not present in the 22-m transmissions because rays of such angles escape through the layer. The values of N given above represent fairly closely the limiting density in the upper layer.

With this data it is possible to plot a curve giving the limiting angle θ as a function of the wavelength. It may be derived from the relation $\cos\theta = R + h/R\ \mu_{\min}/\mu_0$

Since knowing $N_{\max}$, $\mu_{\min}/\mu_0$ is known for every wavelength. This curve is shown in Fig. 4.

It will be observed that it meets the x axis at 8.6 m. Implying that for wavelengths less than 8.6 m the relation above cannot be satis-

fied because even glancing angle rays of higher frequencies are not sufficiently bent to come to earth.

8.6 m is in fact the short-wave day limit.

This acts as a check on the values of N, for we find, in fact, that this is very close to the day-wave limit. Thus 10-m waves transmitted in England have been received in Australia, New York, and Buenos Aires.

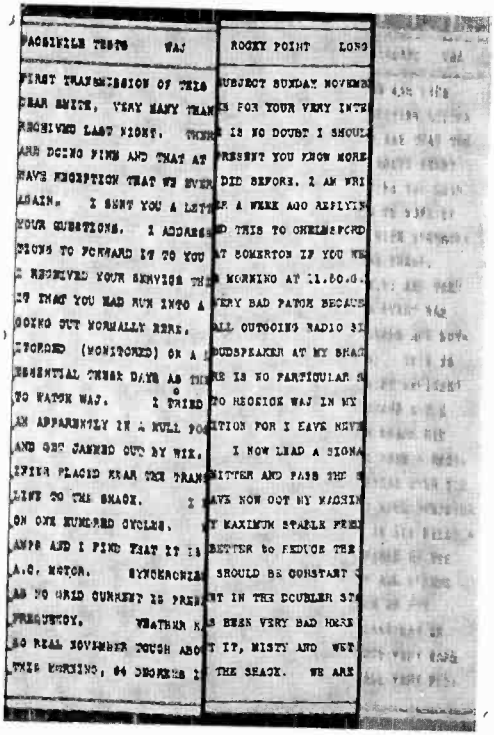


Fig. 10—Specimen taken November 8, 1928 at 1415 G. M. T., Somerton. Speeds: 1st column, 150 cycles; 2nd column, 100 cycles; 3rd column, 300 cycles. Showing increased echo-signal separation with increased scanning speed.

Sporadic and very occasional reception of an 8.67-m beam at Poldhu has been recorded in New York. Reports of occasional long-distance transmissions on waves shorter than this have been received, but definite instances of such transmissions appear to be wanting, and they are probably exceptional.

We may therefore say that there is considerable evidence that the short-wave limit lies between 8 and 10 m in confirmation of the above.

Experiments with a balanced frame and vertical setup to determine the ray angles from the 28 to 32-m Dutch stations, though not of a high order of accuracy on account of the blurring of the balance point by scattered energy, also provide confirmatory evidence.

The angles found lie between 50 deg. and 68 deg. and the corresponding maximum densities (which can be determined independently of the value of x) lie between 8.4×10^5, and 1.3×10^6 with a mean 9.3×10^5, a figure slightly greater than that determined from the echo measures, i.e., 8.43×10^5. Considering the relative inaccuracy of these experiments the agreement is as good as could be expected.

The mean height of the layer determined from these values of θ is 250 ± 55, which lies between the limits set out previously.

These results giving the limiting density of the upper atmosphere seem to rest on a very secure basis and to be much more definite than previous deductions of the layer density in the Heaviside layer. This maximum density it will be observed is derived for full daylight conditions.

The curves (Figs. 1 and 5) show, on the same reasoning as previously given, that the maximum echo time decreases throughout the night, and it follows that the density decreases during the night hours and is a minimum just before sunrise.

The absence of rays of higher angle than 35 deg. has been attributed to the insufficiency of electrons.

It is certainly a Heaviside layer effect as the θ_{min} depends on the local time and is very much less at night.

The only other effect besides electron limitation which can limit θ is attenuation which, however, is likely to be reduced the higher the ray angle, so that the electron limitation hypothesis seems almost unassailable.

In Fig. 4 we have plotted the maximum ray angle as a function of λ, but this maximum ray angle also gives by relation (1) the maximum echo time; we can therefore plot the maximum possible echo time (max. duration between main and echo signal) as a function of λ. This is given in Fig. 6 for daylight conditions. It will be seen that it decreases very rapidly with λ and *is only about 0.8 millisec. at* $\lambda = 16m$. This has a very practical significance in facsimile working.

The maximum echo lag on a 16-m transmission to New York is likely to be only 1/5 of that on 22 m.

Four or five times the speed of picture transmission could be used on such a service.

(This is neglecting scattering echoes which do not seem to be serious in the picture service, at least on 22 m and when signals are relatively strong.)

Summarizing, we may say that this conclusion is logically reached contingent on the two assumptions.

(1) That the main signal (first received) is transmitted at practically glancing incidence.

(2) That the lag of the last echo is limited wholly by insufficiency of electron density in the upper layer, both of which seem to be open to very little criticism or doubt.

Origin of the Multiple Echoes

So far we have been considering the time interval between the first and last signal giving the maximum transmission angle and the maximum density in the layer.

The individual echo signals, as has already been stated, are rather irregular; there is the possibility that they may overlap, in some cases producing phase opposition which obscures the main position of the echo signal. Cases have been found where, however, the echoes are so definitely repeated that they represent without doubt the true sequence of the echoes. Those are represented in Fig. 2.

They represent a set of five signals each implying a definite ray starting in the five definite directions $\theta_1 < 5$deg.; $\theta_2 = 16$ deg. 45 min.; $\theta_3 = 21$ deg. 34 min.; $\theta_4 = 29$ deg. 32 min.; and $\theta_5 = 34$ deg. 36 min.

The question arises, what is the path of these different rays?

The simplest supposition is that they represent the multiple reflection between earth and Heaviside layer, and the internal evidence for this seems fairly strong. This hypothesis is represented diagrammatically in the figure below (Fig. 7) where four rays are separately represented by the four lines $\theta_2 - \theta_5$.

If the upper layer were so well defined that the apex of each of the rays, or rather the equivalent height defined by the apex of the triangle (at B) is the same for all rays, then the height calculated by the triangulation of each of these rays should be constant.

This triangulation may be carried out as follows:

Suppose according to our hypothesis that the fifth signal is by the ray which cuts up the distance d into five equal parts; then the elementary triangle to be calculated is shown in Fig. 7. θ_0 is given by the delay time, d_0 is one fifth d, the distance between receiver and transmitter, the height h is then determinate, and is given by the relation

$$x = \frac{h}{R} = -\frac{\sin^2\theta}{2} - \tfrac{1}{2}\sqrt{\sin^4\theta + 4y^2 - 4\sin^2\theta}.$$

where θ is the angle which d_0 subtends at the center of the earth, and $y = d_1/R$ where d_1 is the length of the ray to the apex B.

d_1 is directly known from the difference in time of the main signal and echo signal. Taking echoes 3, 4, and 5 we get the corresponding values of h'

No. of Echo	h
3	343
4	338
5	340

No. 2 echo is less accurately determined and as it will be more affected by its passage through the lower layer (100 km) it is therefore not included.

The extraordinary consistency of the three independent measures of h in this table makes it very probable that the hypothesis of multi-reflection between the earth and Heaviside layer is correct, the rays at any angle reaching the same virtual height.

In confirmation of this we have the results of Kenrick and Jen,[1] who in a 67-m transmission with the pulse method have indicated a layer at this height. (344 km) (This layer appears to be exposed to a 67-m wave only at night.) See Fig. 3.

This of course is not conclusive, but the agreement seems more than accidental.

These facts would seem to imply that the bending of the ray takes place in a very limited height (of the order of the discordance of the values obtained for h).

It follows therefore that for waves of frequency large compared with 3×10^6 (the critical frequency for the lower layer) the ray paths are very approximately the triangles exhibited in Fig. 7 with only a slight deviation near the apex.

The triangle will be approximately the same for all waves in the range which satisfy this condition, i.e., $\lambda \ll \lambda_0 = 100$ m, and therefore the time lags of individual echoes should be practically independent of the wavelength. The effect of a reduction of wavelength is therefore to reduce the number of echoes but not materially to alter the time between individual echoes.

Short-Wave Attenuation

The information disclosed by the facsimile echo measurements has a great significance with regard to short-wave attenuation in the range between 14 and 50 m.

Take the typical example of the 22-m wave. A typical ray has an angle of elevation between 0 and 30 deg. Consider one with an angle

of about 20 deg. It passes along nearly a straight line at 20-deg. elevation, through the lower layer at 100-km height and is bent back at B (Fig. 7) to earth again. It is the region near the 100-km layer which is attenuating. It passes almost straight through this attenuating layer. (It can only suffer 5-deg. deviation in the layer N being so small.) The total attenuation that the wave will suffer is

$$x=\lambda^2\int\frac{1}{{}_s\lambda_0 c\tau_s}ds$$

where ${}_s\lambda_0$ and τ_s are the values of λ_0 and τ (the time between collisions at a distance S measured along the ray.) ${}_s\lambda_0$ and τ_s are only functions of the state of the Heaviside layer.

So that $\alpha=K_s\lambda^2$.

Now it is obvious from the geometry of the system that the ray will be the same for any other wavelength (within the range considered).

The attenuation will therefore be proportional to λ^2. This is precisely what is found on analyzing the results obtained in the year's interception at Broomfield (for daytime transmission). We have in these results a rational explanation of the behavior of short-wave day attenuation.

Night Transmission

The information as regards night transmission is less definite. The following conclusions, however, appear to be pretty certain.

We have found that the echo delay time decreases throughout the night, being a minimum just before sunrise. This may be definitely interpreted as a gradual decrease of the maximum ionic density N_{max} in the upper layer as the night progresses. But N_{max} determines the short-wave limit for transmission according to the relation

$$\frac{\mu_{1\min}}{\mu_0}=\frac{R}{R+h}$$

or

$$1-\frac{N_{max}e^2c^2}{\pi mn^2}=\left[\frac{R}{R+h}\right]^2$$

or

$$\frac{N_{max}e^2\lambda^2}{\pi mn^2}=1-\left[\frac{R}{R+h}\right]^2$$

$$\fallingdotseq 2x$$

or $$\lambda^2_{\min} = \frac{2 \times \pi m}{N_{\max} e^2}$$

and the smaller the value of $N_{\max}$ the greater $\lambda_{\min}$.

We should therefore expect a progressive increase in the short-wave limit as the night progresses. Thus in the early evening shorter waves can be used for long distance transmission than in the later hours of darkness. This is a well-known fact derived from the analysis of the results obtained in the year's interception.

We can give approximately the values of λ limit as a function of the time elapsed from sunset. Thus see Fig. 5.

	Hours after sunset.	λ	N
approx.	0	8.6	9.3×10^5
	2.5	11	6.5×10^5
	7	14	4.2×10^5
	10.5	20	2×10^5

from the echo delays we have the values

6	4.8×10^5
7	4.2×10^5

in rough agreement with the above.

We may picture the effect somewhat as follows:
As the time after sunset increases N decreases, the maximum ray angle consequently decreases and the useful fraction of the energy radiated, i.e., from $\theta = 0$ up to $\theta = \theta_1$, decreases and consequently the signal strength decreases.

The relation between signal strength and echo delay and consequently $\theta_{\min}$ is strikingly given in Fig. 1.

The controlling factor determining signal strength at night is electron limitation and not attenuation, and to complete the theoretical aspect we should give reason why the attenuation appears to be negligible at night. The reason appears to be that the attenuating layer (100 km) rises at night, effectively increasing τ perhaps tenfold; also N decreases, both of which factors decrease attenuation.

Summarizing we may say that the picture transmissions indicate the presence of four or five or even, in extreme cases, six separate rays between New York and Somerton (on 22 m).

From the measured delay time between the echoes we may state that the maximum angle of elevation of the rays is 35 deg. in all but exceptional cases, and that the main energy is transmitted along rays less than 20-deg. elevation, i.e., practically glancing incidence.

The maximum daylight density in the upper layer is approximately 8.3 to 9.3×10^5 electrons per cu. cm, which corresponds to a daylight minimum wave of 8.6 m.

The total echo delay (between first and last signal) decreases rapidly with the wavelength being 1 millisec. at 16 m and decreasing to zero at 8.6 m.

With less certainty we may conclude that

(1) Transmission takes place by multiple reflections between earth and Heaviside layer, the latter being fairly sharply defined—for this wavelength—at a height of 340 km.

(2) In the daytime attenuation takes place in the lower layer (100 km height) and is practically proportional to λ^2.

(3) Throughout the night the attenuation proper ceases to play an important part, but the limiting wavelength increases (on account of recombination) from 8.6 to nearly 20 m in extreme cases of long winter nights.

List of Symbols Employed

R = radius of earth
n = frequency
n_0 = critical frequency of medium
e = charge on electron
m = mass of electron
N = number of electrons per cu. cm
c = velocity of light
μ = refractive index

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A CONDENSER BRIDGE FOR FACTORY INSPECTION OF VARIABLE CONDENSERS*

By

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Summary—*A capacity bridge designed for routine factory testing of variable air condensers of the "gang" type, as used in modern radio receivers, is described in this paper.*

Setting the bridge involves a capacity balance and a phase-angle adjustment. The capacity balance is effected by a balancing condenser which gives directly the capacity difference between two condensers connected to the bridge for test. The phase-angle adjustment is made by rheostats in series with the condensers, and by an arrangement whereby the phase angles of the ratio resistances can be varied slightly for precise adjustment.

Design and construction of some of the more important parts, and testing and calibration of the bridge, are described, and installation and use of the bridge are discussed.

WITH the development of gang condensers for single-control tuning there has arisen the problem of the development of suitable factory inspection apparatus for these condensers. The first requirement of apparatus of this nature is accuracy. It is perhaps obvious that the accuracy of inspection apparatus which is to be operated by factory workers must be considerably greater than that of the measurements to be made. It is neither possible nor desirable to require the inspector to make precision measurements in order to determine the accuracy of the condenser. It seems more desirable to build inspection apparatus capable of great precision and to use it carelessly than to build apparatus capable of less accuracy and be compelled to make precision measurements with it.

It should be pointed out that this problem is not strictly one of precision measurement, but rather one of precision comparison. It is permissible for the capacities of the condenser units of any one receiver to differ from those of another receiver by considerably greater amounts than the capacities of the condenser units of any one gang may differ from one another. It is seldom that the individual receivers must calibrate alike within one per cent. What is required is a device which will determine with great precision whether or not two condensers are equal, and which will, if they are not equal, measure the difference with a fair degree of accuracy.

* Dewey decimal classification: 621.6.

The apparatus should be completely self-contained, with no external standards which might get out of adjustment through mishandling or accident. It should be rapid in operation. It must be so designed that it may be operated by non-technical labor, and its use must not be tiring to the operator. There should be little or no hand or body capacity effect. The apparatus must also be capable of readily checking the condensers at all points of their range.

Three types of inspection apparatus for this service are in common use. One type utilizes a radio-frequency oscillator, and the measurements are made by comparison with a standard capacity, using a tuned

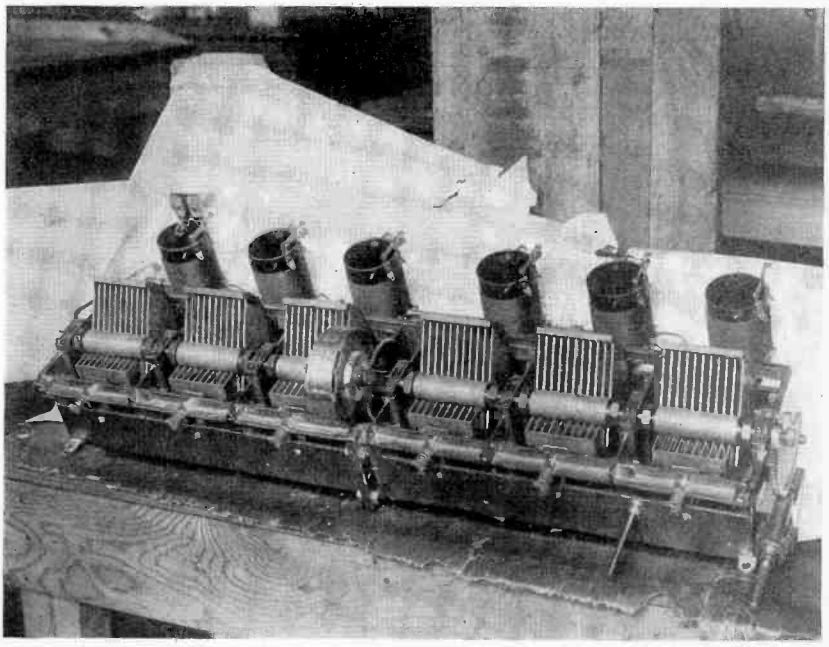

Fig. 1

circuit and a resonance indicator. A second type utilizes two radio-frequency oscillators, and the measurements are made by comparison with a standard by the adjustment of the beat note between the oscillators to zero. A third type employs an impedance bridge at audio frequencies, the measurement being made by a direct balance. Of these three, the last meets to the best advantage the requirements stated above, and in addition has the added feature that, as no radio-frequency oscillators are used, shielded rooms are not required to prevent interference with other testing operations which do involve radio-frequency currents.

In 1925 the authors were confronted with the problem of building a device for the factory inspection of a gang condenser of six units. The individual condensers of this "gang" were required to stay "in step" within a limit of 1 $\mu\mu$f. The condenser (shown in Fig. 1) was so designed and assembled that accuracies of this order might be expected

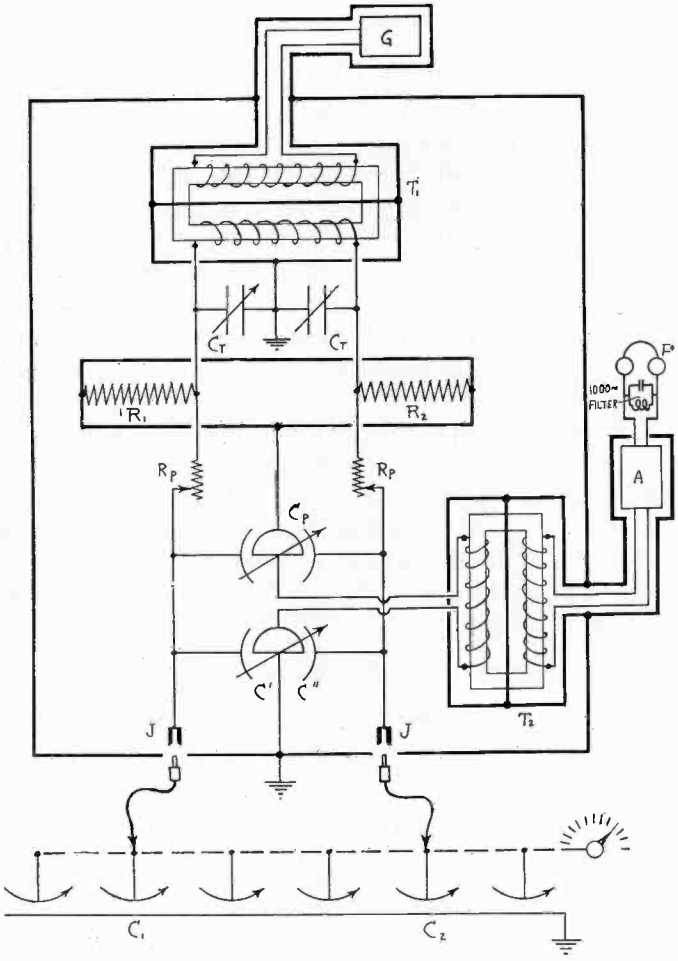

Fig. 2

directly from the assembly lines, and it was contemplated that the duties of the inspector would be largely to check the accuracy of the various condensers in the unit. Nevertheless, it was desirable to construct the inspection apparatus so that minor adjustments to the condensers could readily be made by the inspector without unduly delay-

ing the inspection operation. After a survey of the various methods, the bridge method was selected as most suitable, and several condenser bridges were constructed which have given satisfactory service since 1925.

These bridges have also been found economical for use in the inspection of smaller and less expensive gang condensers, and it is believed that a description of the apparatus will be of general interest.

General Description

A complete circuit diagram of the bridge and associated apparatus is shown in Fig. 2. The four arms of the bridge consist of the two ratio resistances R_1 and R_2, and the two capacities (C_1+C') and (C_2+C''). There are also two rheostats (R_P) connected in series with the two condenser arms, and the double stator condenser C_P is connected across the two ratio arms. Current is supplied by the 1000-cycle generator, G, through the transformer T_1, and the phones (P) used to detect balance are connected through the transformer T_2 and the amplifier A. The two condensers C_T constitute a zero adjustment which will be explained later.

The condensers C_1 and C_2 are two units of the gang condenser undergoing test. They are connected in parallel with the two bridge capacities C' and C'', respectively, by two leads which plug into the jacks J.

The manipulation of the bridge will be described in detail later. At this point it is sufficient to point out that the two ratio resistances are equal, and hence the two condenser arms must be made equal to balance the bridge. That is,

$$C_1+C'=C_2+C'' \tag{1}$$

and hence, if C_1 and C_2 are unequal, C' and C'' must be adjusted to the same inequality. The difference between C_1 and C_2 is then read on a scale attached to C' and C''.

Conditions for Accurate Balance

The equation for the balance condition given above neglects the reactances of the ratio arms and the resistances of the condenser arms. It can be shown that the conditions for balance are given exactly by the two expressions

$$\frac{Z_1}{Z_2}=\frac{Z_3}{Z_4} \tag{2}$$

and

$$(\phi_1+\phi_4)=(\phi_2+\phi_3) \tag{3}$$

where

$$Z_1 = \sqrt{R_1^2 + X_1^2} \quad \text{etc.}$$

$$\phi_1 = \tan^{-1} \frac{X_1}{R_1} \quad \text{etc.}$$

The subscripts 1 and 2 refer to the two ratio arms, and 3 and 4 to the condenser arms of the bridge circuit (See Fig. 7).

It can also be shown that in a condenser bridge with resistance ratio arms, small variations in the phase angles of the arms can be made without affecting the impedances. Also, the impedances of the ratio

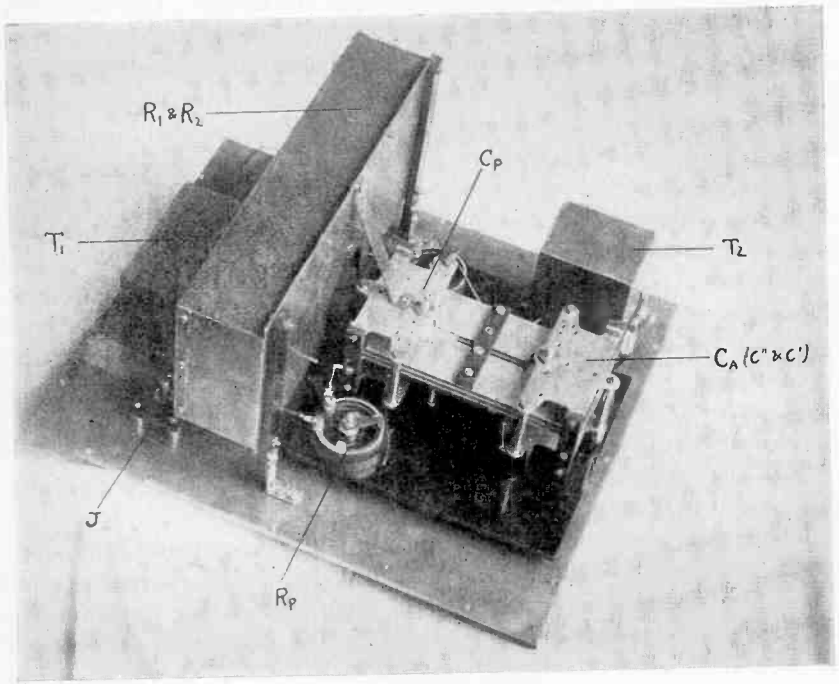

Fig. 3—Interior view of bridge. The condensers $C_T - C_T$ are beneath the stator plates of C_P and C_A.

arms are practically equal to their resistances, while the impedances of the condenser arms are indistinguishable from their reactances. Equation (2) may therefore be rewritten

$$\frac{R_1}{R_2} = \frac{X_3}{X_4} = \frac{C_4}{C_3}, \tag{4}$$

The bridge is balanced by making C_3 equal to C_4 to satisfy (4) (since R_1 and R_2 are equal) and adjusting the phase angles to satisfy (3). In case (3) is not exactly satisfied, the adjustment of the balancing condenser to satisfy (4) is not sharply defined, and the sound in the phones is not completely balanced out. It is important, therefore, to have very accurate control of the phase angles when exact measurements are desired.

Capacities between various parts of the bridge and earth may affect the balance unless suitable precautions are taken. The most important earth capacities are those of the generator, as they are generally unsymmetrical about the electrical center of the output circuit. It will be noted that without the input transformer, T_1, the generator earth capacities would be across the two arms of the bridge. The inequality of these added capacities could be corrected for easily, but the unequal capacities in combination with the large phase differences of the generator earth capacities would produce a serious disturbance which would be difficult to correct for. By interposing a shielded input transformer between the generator and the bridge, the generator earth capacities are eliminated from the circuit. Obviously, the transformer has earth capacities, but careful construction makes the earth capacities of the two secondary terminals closely alike, and the small residual unbalance is readily corrected by the two condensers C_T shown in Fig. 2.

These same compensating condensers also serve as a zero adjustment by which slight differences between the capacities to earth of the two sides of the bridge are balanced. There is also generally a slight shift with temperature changes, which is taken care of by occasional checking of the bridge with all external capacitive connections removed. One of the compensating condensers is provided with an external adjusting screw, which is shown in Fig. 4.

The input transformer earth capacity is quite large, and is not generally evenly balanced. Although the condensers C_T compensate for this capacity unbalance, there is still some phase-angle unbalance in the transformer which is balanced out by two adjustments which will be described next. Referring to (3), it can be seen that there is no theoretical objection to obtaining the phase-angle balance by varying any one of the four phase angles involved, or any combination of them, so long as the phase angle is not swung so far from 0 deg. (in the ratio resistances) or from 90 deg. (in the condensers) that the phase angle and the impedance cease to be practically independent. In this bridge the adjustment is actually made by varying all of the phase angles. Two small non-inductive rheostats, R_P, in series with the condenser arms control ϕ_3 and ϕ_4, and a condenser C_P across the resistance arms con-

trols ϕ_1 and ϕ_2. C_P is arranged to throw a small variable capacity across either ratio resistance, and thus provides fine adjustment of the phase angles, while the rheostats are used for coarse adjustment. The condenser C_P is referred to hereafter as the phase-angle condenser.

A great advantage resulting from the use of two devices for phase-angle control is that the phase-angle balance can be held through the

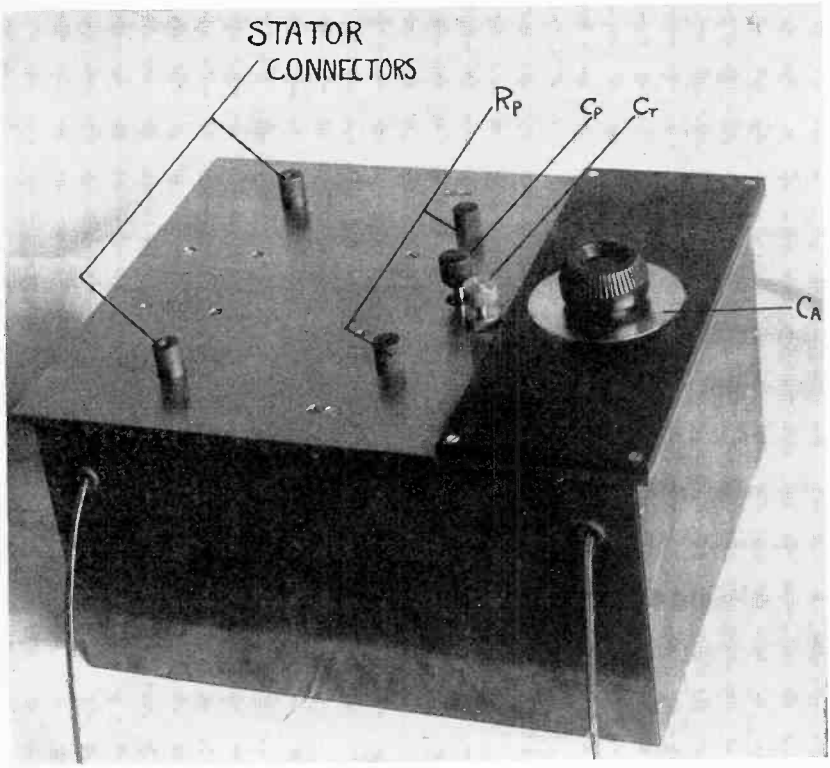

Fig. 4—Exterior view of condenser bridge. C_A = balancing condenser C_T = transformer equalizing condenser. R_P = rheostat. C_P = phase-angle condenser. J = plug and jack for connection to condensers under test. The photograph was taken before the capacity-difference scale was engraved on the bakelite panel.

range of variation of the external capacities (the condensers under test), so that the operator in making his measurements has only to adjust the balancing condenser with one hand while he swings the external capacities from minimum to maximum, the rheostats and phase-angle condenser being left fixed. This result could not be obtained if either phase adjusting device were used alone. A useful addition, which

could not be used in this bridge because of space limitations, is a pair of equal fixed air condensers, having capacities of about 100 $\mu\mu$f, shunted across the condenser arms of the bridge so as to raise the minimum capacity of these arms to something over 100 $\mu\mu$f. Such an addition reduces the difficulty of maintaining the phase-angle balance for various capacities under test.

It will be noticed that if the bridge had been grounded at the junction point of the two ratio arms, according to the usual practice, instead of at the junction point of the two condenser arms, most of the

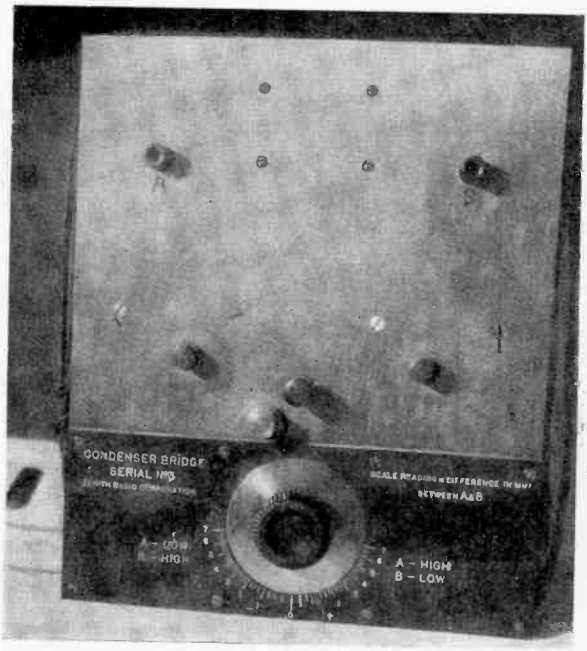

Fig. 5—Top view of bridge, showing capacity-difference scale.

difficulty described above would have been avoided, for the input-transformer earth capacities would then have been shunted across the ratio arms. With the bridge grounded in this way the condenser rotors would be ungrounded, however, and the operator would disturb the balance whenever he moved his hand near the condenser. Also, since the operator is capacitively coupled through the head phones to the output of the amplifier while the condenser rotors are coupled to the amplifier input circuit, feed back from output to input would occur whenever the operator touched a rotor or the condenser frame to make adjustments or to vary the capacity. The resulting audio-frequency

howl would be extremely troublesome, as well as tiring to the operator. Grounding the condenser side of the bridge prevents such feedback.

Details of Design and Construction

In this section there will be discussed only those elements which especially require detailed description. The foundation of the bridge proper is a heavy brass plate, on the lower side of which are mounted the parts shown within the shield in Fig. 2. The generator, amplifier, and filter are located externally at some distance from each other, to reduce shielding difficulties. The construction is shown quite well in Figs. 3 and 4. Especial care was taken in the design to make all parts, including the top plate, extremely rigid, so that the strain incident to placing the bridge in the testing bench would not throw it out of adjustment.

Ratio Resistances

The two ratio resistances are wound in a single layer on a strip of bakelite 1/32 in. thick and 3.5 in. wide, and are coated heavily with paraffin to protect them from moisture. Each resistance is about 3000 ohms. This type of winding, though not strictly non-inductive, has low enough inductance to satisfy the requirements of this particular bridge. The bakelite winding strip is rigidly spaced within its shield so that its position and hence the capacity cannot change. The shield is supported and insulated from the panel by two insulating strips. Especial care was found necessary in selecting the best insulating material for this purpose. The construction can be seen in Fig. 4, and Fig. 3 shows the actual arrangement of the wiring. The two distant ends of the resistance windings are connected together through the shield, and the terminals are brought out from the center of the winding strip. This construction permits the wires between the input transformer, ratio resistances, and balancing and phase condensers to run along the center of the panel, where their capacity to earth cannot be affected by bending or warping of the outside shield, and also facilitates reversing the input transformer and ratio arm connections for testing.

Transformers

The input and output transformers are alike in construction, the only difference between them being in the impedances of the windings. The primary winding of each was wound next to the core in two equal sections, which were placed on opposite legs of the core and connected in series. Around each primary section a piece of copper foil was wrapped, and the secondary was wound over the foil, also in two equal sections. The copper foil constituted an electrostatic shield between the windings.

The winding impedances were selected to match the bridge impedances to the generator impedance and the amplifier input impedance. Over each transformer is a copper shield making tight connection with the panel. The transformers are placed at opposite ends of the bridge so as to reduce the coupling between them, and the division of the windings into two parts is relied upon to reduce the coupling to a low value. With these precautions, the copper shields are able to reduce the remaining small coupling to zero.

Rheostats

The rheostats in the condenser circuits, being on the high potential sides of the condensers, must be small, well separated from the shield, and symmetrically placed, so that their capacities to earth, which shunt the condensers under test, will be small and equal. The rheostats used are about the size of vacuum-tube filament rheostats, but use a carbon-impregnated strip as a resistance element. Their range is approximately 50 to 2000 ohms. They can be seen in Fig. 3 on each side of the phase-angle condensers. All metal parts of the rheostats, including the shafts to which hard rubber knobs are attached, are an inch or more below the top panel. This has been found sufficient to prevent any disturbance when the operator touches the knobs to make adjustments.

Balancing and Phase-Angle Condensers

The balancing and phase-angle condensers are built in the form of a single unit containing two sets of rotor plates for the two condensers and a single pair of stator elements common to the two condensers. This condenser unit can be seen in Fig. 3.

Since the balancing condenser in particular is subjected to constant use, it requires bearings which do not wear appreciably and which allow the shaft to turn freely without permitting even the slightest end-play or side-play. The best arrangement is to use a steel ball at the lower end of the shaft, pressing the shaft firmly against it with a spring in the upper bearing, and to make the upper bearing in the form of a split sleeve which fits the shaft snugly. Such bearings have been found to be much better than cone bearings.

When the condensers under test are very nearly equal, say within 1 or 2 $\mu\mu$f, the difference between them must be accurately measured, but when the difference is greater, less accurate measurements will suffice. The stator plates are therefore so shaped as to spread the scale out at the center and compress it at the ends. This is shown in Fig. 5, which is a top view of the bridge. The maximum capacity difference that can be measured is 7 $\mu\mu$f.

Testing and Adjustment

Ratio Arms

The ratio arms were measured in an Anderson bridge and adjusted to be as nearly equal as possible, and then were allowed to season for several weeks before being used. When the bridge was completed and connected for final testing, the ratio arms were again checked by reversing them. Although accurately adjusted resistances are likely to vary as they age, it was found to be possible to adjust the ratio resistances so that they would stay within one-half an ohm of equality. This is quite satisfactory, since it results in an error of only 1/60 per cent, or a maximum capacity error of 1/15 $\mu\mu$f.

Stray Coupling

Stray coupling between the input and output circuits may occur directly between the generator and amplifier, between the input and output transformers, or between the leads. Such coupling, if it exists, is plainly evidenced by current flowing in the telephones when the input and output transformers are disconnected from the bridge. By making separate tests with the input and output transformers merely disconnected from the four corners of the balancing network, with the leads disconnected at the transformers, and with the leads disconnected at the generator and amplifier, it is possible to determine the source of stray coupling. In these tests it is necessary to avoid any electrostatic coupling between the leads, such as might be caused by exposing the ends of disconnected wires.

Input Transformer

The necessity for balanced input transformer windings has already been explained. Lack of balance was demonstrated by the failure of the bridge to balance properly,—more specifically, by the failure of the phase-angle condenser to effect a sharp balance with small external capacities. The remedy was to replace the input transformer with a new one, having more accurately constructed windings.

Calibration

Calibration was carried out by connecting two finely adjustable variable condensers to the bridge, adjusting them to exact equality, and then changing one in small known capacity steps, at each change balancing the bridge circuit by adjusting the balancing condenser. The points so obtained were engraved on the bakelite panel surrounding the dial.

Installation and Use

The condenser bridge, with its associated apparatus, is set up for use in the factory by mounting on a special bench. The bridge is set flush into the top of the bench, with the dial nearest to the operator, as shown in Fig. 6. The generator and amplifier are placed in separate iron boxes on a shelf below the bench, and are several feet apart. All wiring, except the output connections to the filter and telephones, is shielded with grounded copper braid. A sliding table is provided above the bridge, upon which the condenser to be inspected or adjusted is placed. Three terminals provided with clips connect to the condenser,

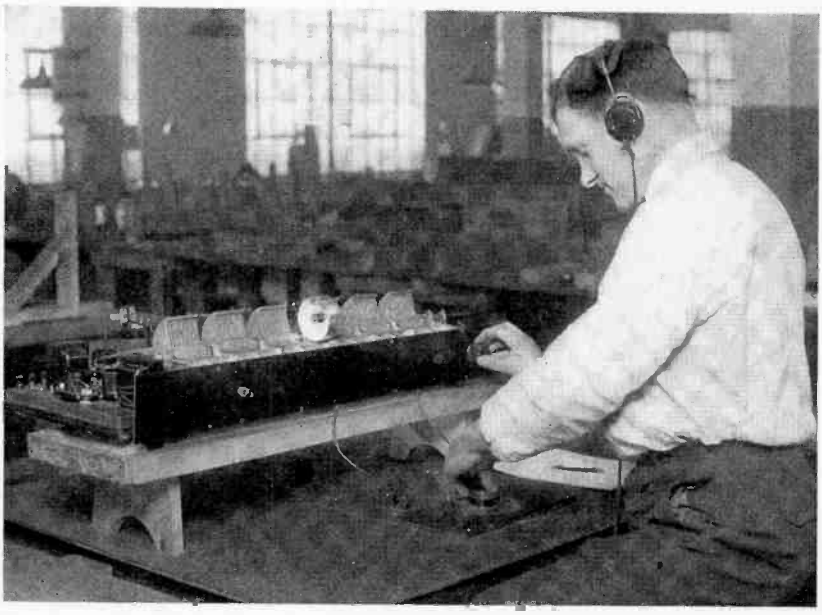

Fig. 6—Condenser bridge in use in factory. The bridge shown here was an earlier model than that described.

one being the ground connection to the common rotors, and the other two the connection to the stators of the two units to be balanced. These leads must, of course, be kept short and rigid, and must not come into close proximity to each other or to other parts of the condenser. The stator connectors are provided with plug terminals which may be removed from the bridge in checking the zero balance.

In operation, the bridge is first balanced to read zero capacity difference with the stator connectors removed, by means of the adjusting knob C_T (Fig. 4). The phase angles are adjusted by the condenser C_P

and the rheostats R_p. The two condenser units to be balanced are then connected to the bridge, and the operator runs the variable condenser over its range with one hand, while the other hand follows the variation of bridge balance with the balancing condenser C_A (Fig. 4). One of the stator connectors is then moved to the stator of another condenser unit and the operation is repeated, thus comparing the capacities of all the other condenser units to that of the first one. If the various units of the condenser are running well within the prescribed limits of accuracy, this is generally a sufficient check on the condensers. If the condensers vary considerably over the range, or if the limits are approached, it is necessary that all the units be checked at the same settings by moving one of the stator connector leads to each of the stators

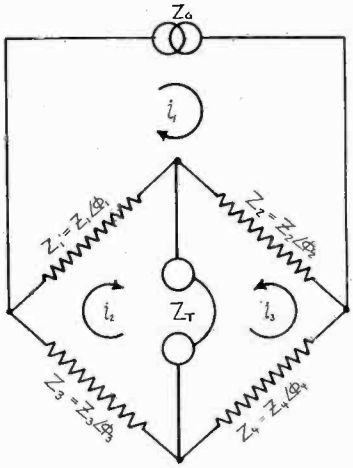

Fig. 7

in succession, thus comparing the capacities at each setting. This is repeated for as many settings of the condenser as seems necessary to insure that no one of the units varies from another by more than the prescribed amount.

It is obvious that if the reference condenser is out of its proper adjustment, all of the other units will appear to be incorrect by these methods of comparison. With the proper mechanical inspection of the condenser before the electrical inspection takes place, it is a relatively simple matter to determine the improperly adjusted units by a hasty check of two or more of the units before any time has been wasted in an accurate inspection of the condenser.

When adjustments are to be made to the condenser units in order to bring about a balance, the procedure is first to determine the improp-

erly adjusted unit, and then to make the readjustment by bending the end plates of the rotor while the condenser is on the bridge. The proficiency of an intelligent operator in adjusting defective condensers in this manner is quite remarkable, and it is possible to correct a defective unit while on the bridge with nearly the rapidity with which a unit may be inspected.

The writers are indebted to J. K. Brown for assistance in the experimental work, and to the officials of the Zenith Radio Corporation for permission to publish this paper.

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HUM IN ALL-ELECTRIC RADIO RECEIVERS*

By
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Summary—*This paper presents the results of some further work in the field of all-electric receivers, directed particularly toward the design of receivers and power-supply systems requiring a minimum of apparatus and providing a maximum of hum eliminating action. It includes the enumeration of the causes of hum, the analysis and measurement of hum, and methods of its elimination.*

I. Introduction

THE present paper is the third of a series covering the results of research and development on electric radio receivers. The first[1] of these was entitled "A New System of Alternating-Current Supply and its Application to a Commercial Broadcast Receiver." This paper traced the development of electrically operated receivers, recited in detail the results of studies of the then commercial d-c vacuum tubes with a-c operated filaments, advanced theories for the hum introduced by this type of excitation, suggested a tube structure better adapted for a-c excitation, and described the first all-electric commercial broadcast receiver; this was the Garod Electric Model E-A.

The second paper,[2] entitled "A Three-Element A-C Vacuum Tube," dealt principally with further hum studies of commercial d-c tubes, and with the first low-voltage, high-current a-c tube of the three-element type suggested in the previous paper, which I had developed in the meantime. It also described another commercial broadcast receiver, the Garod Model E-M, in which this tube was used throughout except in the power stage.

II. Causes of Hum in Electric Receivers

There are many possible causes of hum in electrically operated radio receivers, some of which require rather careful and painstaking effort for location and elimination as a design problem; these may be classified under three general heads as follows:

*Dewey decimal classification: R343.7. Presented before meeting of the Rochester Section of the Institute, April 19, 1929.

[1] *Radio Broadcast*, February and March, 1926, and *Proc. Radio Club of America*. Presented before Radio Club of America at Columbia University, September 22, 1926.

[2] *Radio Broadcast*, September, 1927, and *Proc. Radio Club of America*. Presented before Radio Club of America at Columbia University, May 18, 1927.

A. Tubes
B. Induction
C. Current Supply to Tube Elements

A fourth which is seldom encountered in well-designed and fabricated sets is omitted from this classification. I refer to the mechanical hum caused by loose laminations or high saturation in transformers or chokes.

A. Tubes

While the hum introduced by tubes is usually beyond the control of the receiver designers, inasmuch as their designs are built around given tubes generally available, or to be available, nevertheless an understanding of the causes of hum in tubes is desirable.

For the benefit, therefore, of those who have not digested the previous literature on this subject, a brief discussion of causes of hum in tubes is here included.

Alternating-current tubes fall at present into two classes, namely, those having three elements, wherein the cathode heating current passes directly through a filamentary cathode; and those having four elements, wherein the cathode is indirectly heated by radiation or conduction from an internal filament conductively, in the electrical sense, dissociated from the circuits of the tube.

The three-element a-c tube may develop hum from several causes, independently or in combination. Among these the most important are:

1. Temperature variation of the filamentary cathode.
2. Voltage, or Edison effect, between the ends of the filament.
3. Magnetic or magnetron effect of filament current on the space current.
4. Unsymmetrical tube structure or emission from filament legs.
5. Improper operating voltages.

1. Temperature Effect

When the filamentary cathode is heated by alternating current the heating power varies from one instant to the next with the instantaneous power of the heating current. Since the heat energy so developed leaves the filament by radiation, conduction, and electron evaporation, it is evident that the temperature of the filament will not be constant. It will vary at a frequency double that of the exciting current frequency and at an amplitude depending upon what I have termed its "thermal inertia." This is a factor determined by the ratio of its heat storage capacity to its heat dissipating ability. The storage

capacity is determined by the specific heat of the filament metal and its cubical contents. The heat dissipation depends upon the radiating surface area, its radiation constant, its temperature, and also upon the nature of absorbing or reflecting objects in its immediate vicinity, and upon conduction effects from the filament ends.

To secure a condition of minimum temperature variation, therefore, the storage capacity of the filament must be high, and its radiation losses low. That is, on the one hand the cubical contents and specific heat of the filament must be high; on the other hand, the radiating surface, radiation constant, and temperature must be low. These relations may be expressed as a ratio which we desire to have as small as may be necessary or desirable to accomplish our purpose:

$$\frac{AT^4K}{VS}.$$

Since the radiation rate varies as the fourth power of the cathode temperature it is very important to use the lowest possible cathode temperature for minimizing the temperature variation.

2. Voltage Effect

The effect first noted in incandescent lamps by Edison is present in three-element a-c tubes as a source of hum. The two-filament ends vary from zero to peak filament potential and reverse with respect to one another at the frequency of the filament exciting current.

The leg positive at any given instant acts as an anode of low voltage, but, without intervening grid voltage, also as a contender with the proper anode for the emission of the other filament leg. The effect of this is the same as if an auxiliary plate supplied with alternating voltage of the filament frequency were placed in the tube along with the steady voltage anode. That is, it periodically substracts, at double the frequency of the filament current, from the proper anode current and therefore develops a hum.

This effect may be minimized by using very low filament voltages compared to plate voltages, by separating the filament ends as far as possible, as by the use of a straight filament, or by an extension of the normal grid which shields one filament leg from the other.

The author has shown in previous papers how this voltage effect may be made to neutralize within the tube a residual temperature variation effect of the type previously discussed.

3. Magnetic or Magnetron Effect of Filament Current on the Space Current

If the alternating magnetic field of the filament current has any

coupling with the steady field of the electron stream, a variable force between these two conducting paths will cause a periodic variation in the path length of the electron stream, which will introduce a corresponding variation in the plate resistance of the tube, having a frequency double that of the filament current. This is in phase with the voltage effect and may therefore be neutralized with the latter by the temperature effect.

4. Unsymmetrical Tube Structure or Emission from Filament Legs

If the plate resistances from the two legs of the filament are unequal due to an asymmetrical structure, or if the emissions of the two legs of the filament are unequal, a hum may be introduced having a frequency equal to that of the filament exciting current. This may occur in a tube whose elements have been considerably displaced, or in a tube previously operated for a long period on direct filament current wherein one filament leg has lost its emission.

5. Improper Operating Voltages

If a three-element a-c tube be operated at high-filament voltages, a voltage or stealing effect hum may appear, and if operated at low-filament voltages, a temperature type hum may appear. If plate or grid voltages are too low, voltage type hum may also appear. The steady grid-bias voltage should always be higher by a factor of at least two or three than the filament voltage to prevent the signal voltage from cutting through it and allowing the grid to become positive. The plate voltage should be high compared to filament voltage so that the voltage effect of the positive filament end will cause a minimum of electron diversion from the plate, and therefore a minimum of hum.

AUDIO AND MODULATION HUM

When the above-described hum causes are present to sufficient degree in detector or audio tubes, a continuous hum will be heard in the speaker. A very small amplitude hum of this type may be objectionable because of the usual practice of tuning out all signals when listening for hum. This same fact applies equally well to other types of hum introduced into the audio system.

When the hum causes are present in radio tubes the hum does not appear until a radio-frequency carrier passes through them. Then, if they are strong enough to vary the mutual conductance of the tube, this radio-frequency carrier will be modulated, and the modulation will be detected and amplified as a hum.

This type of hum is many times erroneously attributed to the broadcast station, since it is heard only when a carrier is tuned in. A simple way to check this by ear for a given set or station is to tune in other strong carriers. If all develop this hum it may rather safely be attributed to the receiver, otherwise the particular transmitter is at fault.

It may be remarked here that the amplitude of this modulation hum is determined both by the amplitude of the modulating causes in the receiver and the amplitude of the carrier in the r-f tubes. Because of this fact the modulation hum is usually masked by program modulation of the carrier at the transmitter, and by microphone, tube, and other noises, originating both at transmitter and receiver. The amplitude of the modulation hum as developed in the loud speaker may be controlled by the usual radio-frequency volume control in the receiver as well as by the tuning control.

The second paper of this series previously mentioned describes in detail the method of measurement of modulation hum and the results of numerous measurements on tubes.

Four-Element Tube Hum

The four-element or heater type of tube eliminates for all practical purposes the temperature type of hum which is present to some degree in the three-element tubes available today. However, there are still present to some degree the sources of voltage and magnetic hum and in addition other hum-producing causes, such as conduction of filament current through the high-temperature insulation between cathode and heater filament.

When all of the above-mentioned factors are properly reckoned with in tube and receiver design,—and certainly no severe limitations need by imposed by them on set designs,—the three-element tube is capable of performance fully equalling that of the four-element tube. The tubes at present available are fairly satisfactory in performance, and are more easily and more cheaply constructed than the four-element type. Although the present construction provides a lower plate capacity in the four-element tube than in the three-element type, it is easily possible so to construct the three-element tube that this condition will be reversed, so that the three-element tube will be preferable for use in radio-frequency circuits to the four-element tube. A straight filament with concentric grid and plate electrodes makes this possible. If, instead of the present one and one-half volt on the filaments, the voltage be reduced to one-half or three-quarters of a volt, as used in the writer's three-element tubes previously de-

scribed and demonstrated, the three-element a-c tube may be made to produce less hum than the four-element type. It may therefore be used for detection, especially with the recent trend of one-stage audio systems and plate type or power detectors.

At a time when all efforts are being bent towards simplification, price reduction, and improved performance in radio receivers, it appears incongruous that tubes should be trending oppositely, as witnessed by the changes in the last few years from three to four and now to five-element tubes.

Under present conditions, receiver designers ordinarily have no control over tube designs, and therefore the hum originating in the tubes themselves must be accepted or neutralized externally. If, however, as now appears probable, receiver manufacturers will also manufacture their own tubes, this undesirable condition will have good prospects of being remedied.

B. Induction

Hum caused by induction is a rather important factor in present-day electric receivers, particularly since the combination of power supply and receiver on one rather compact chassis has become the design standard. While the older plan, using a separately housed power supply, reduced the likelihood that this type of hum would be objectionable, it by no means eliminated it, particularly if the choice of power box location with respect to the receiver was left to an unskilled user or installer.

Induction hums may be separated into two classes due to:

1. Magnetic induction
2. Electrostatic induction

1. Magnetic Induction

While the power transformer is usually the worst offender with respect to a-c leakage field, there are also other important sources which must not be overlooked. Among these particularly is the first filter choke. This choke, unless preceded by a very large condenser, carries an a-c component of considerable magnitude superposed on its already saturating d-c component. This, coupled with the use of air-gaps in the magnetic circuit to reduce saturation for maximum inductance, sets up a rather strong a-c leakage field. Due account must be taken of this in the physical design of the receiver.

Of less importance, yet still to be considered, is the a-c magnetic field set up by other chokes such as the output coupling choke sometimes used for speaker circuits, and output transformers, which,

because of no succeeding amplification, may carry a considerable filter ripple component without developing objectionable hum in the speaker.

Filament feeder leads carrying several amperes of alternating current may cause some hum if run very close to the first audio transformer of a good two-stage amplifier. Only in such cases need the two feeder leads be twisted. The twisting of these filament supply leads has unnecessarily been much overdone in the past.

It is hardly necessary to state that the first audio transformer in the usual two-stage audio system is the most susceptible target for these alternating leakage fields. This is easily understood when it is remembered that any alternating voltage introduced therein will be amplified ordinarily about a hundred-fold by the succeeding amplification. Good amplifiers, of course, demand greater care in layout with respect to induction than poor ones. A poor amplifier may have but little amplification at the predominant frequency of 120 cycles obtained with the usual full-wave rectifier, while at 60 cycles it may be practically nothing. Consequently power transformer induction requires but little consideration, unless power line harmonics, or harmonics introduced in the transformer itself, are large enough to cause saturation. In this case higher frequencies capable of good amplification by poor low tone amplifiers are picked up and amplified to objectionable proportions in the loud speaker.

High-quality amplifiers require extreme care in respect to induced hums. I recall one particular amplifier in a broadcast receiver which picked up and amplified into a loud hum the 60-cycle magnetic field of an alternating-current soldering iron at 2 feet distance!

While the first audio transformer is naturally the most susceptible to these stray alternating magnetic fields, the second transformer must also be given some consideration. It must further be remembered that the electron streams in the tubes themselves are as susceptible to the magnetic fields produced by external sources as they are to the fields of the internal filament or heater, and must therefore not be unduly exposed to them. This applies especially to the tubes in the detector, first audio, and radio-frequency stages.

Not to be forgotten here is the electrodynamic speaker. The present speakers of this type, when supplied with unfiltered or poorly filtered field current, develop a strong hum caused by induction into the moving-coil circuit of alternating currents produced by the alternating component of the field current. Also the field coil and frame possess a strong a-c leakage field under this condition and must therefore be kept at a distance or properly oriented with respect to those parts of the receiver affected by such fields.

Separately excited speakers sometimes also develop hum caused by induction from the field magnetic circuit to the signal input transformer, or from the rectifier power transformer to the input transformer. I have in mind one of the most recent designs of an important dynamic speaker manufacturer in which this last condition was found in pronounced degree. The induction hum in dynamic speakers caused by the pulsating field current has in the past caused considerable hum troubles when used with receivers otherwise free of hum. The usual methods of reducing this hum by bucking coils, shading rings, and condensers are not very satisfactory. Measurements which I have made indicate that the normal bucking coil will reduce the induced current in the moving-coil system only to about one-third of its un-neutralized value; a heavy copper shading ring will reduce it to about one-half; a 2000-μf condenser of the dry electrolytic type, in the case of a low-voltage rectifier type of field supply, will reduce it only about 30 per cent.

The writer has perfected several neutralizing methods for this type of hum in dynamic speakers, having neutralizing factors of the order of 500. These will be described in detail at some future time.

2. *Electrostatic Induction*

Hum caused by induction of low-frequency electrostatic fields arises almost wholly in the audio system, that is, in the detector and audio-amplifier circuits. The radio tubes have very low audio-frequency impedances from grids and plates to ground and therefore have low sensitivity to these fields.

Hum of this type occurs mostly at the higher audio frequencies because of the fact that the amount of electrostatic coupling commonly present favors them. Any unshielded conductor carrying high alternating or pulsating voltage components may act as the source of these disturbing hums. Chief among these are the rectifier tube and its associated filament and plate-supply circuits, the wiring and devices associated with the input side of the filter, and the primary circuit of the power transformer. These have pulsating or alternating voltage components of considerable magnitudes above ground potential, and therefore produce rather strong electrostatic fields. The rectifier circuits require particular attention because the rectifier tube distorting characteristic develops considerable voltages at higher audio frequencies, which are favored by the fixed electrostatic couplings and by the higher amplifying ability of the receiver.

Although gaseous type rectifiers have been practically abandoned in present designs, it may be remembered that they usually introduce

in addition to the audio-frequency hum effects above mentioned, radio-frequency disturbances capable of affecting the radio end of the receiver. Care must therefore be exercised in their use with respect to this characteristic.

As with magnetic induction, the chief targets for the low-frequency electrostatic fields lie in the detector and first audio stages. With the now customary grid detection, the grid of the detector tube and the grid ends of the grid leak and condenser connected to it are separated from ground potential by very high audio-frequency impedances, namely, the grid leak and condenser, so that these portions of the detector input circuit are highly susceptible to audio-frequency electrostatic fields. Suffice it to state that a capacity of the order of 1 $\mu\mu$f between this grid input and the rectifier filament or plates, or some other of the previously mentioned sources, may cause an entirely objectionable hum to appear in the reproducer. I have in mind a broadcast receiver which had a very objectionable buzzy type of hum because the detector tube was mounted within a few inches of the rectifier tube.

To lesser degrees the detector leads and first audio grid leads are also subject to this type of induction. The degree of susceptibility, of course, is determined by the amount of amplification following the induction input point.

Unless the filament of heater windings of the audio or detector tubes are very close to ground potential, that is, with but little or no audio-frequency impedance between them and ground, capacitive coupling between the rectifier windings and these filament windings in the power transformer may introduce hum, particularly in the detector stage.

C. Current Supply to Tube Elements

Omitting the filament supply current which has previously been discussed as a hum cause in receiver tubes, it is clear, I believe, that unsteady plate or grid voltages caused by insufficiently filtered current supply are a very common cause of hum in electric sets.

The question of the current supplied to plate and grid circuits as a design problem for most effective use of a given amount or cost of apparatus has apparently not found its most effective solution in many receivers now available.

While not actually a part of the power-supply apparatus, the filament or heater potentiometers may introduce hum-producing voltages in the grid or plate circuits of the receiver tubes if improperly adjusted or fixed. While the early electric receivers were equipped with

two or three variable filament potentiometers, the most recent tendency has been to use fixed potentiometers or mid-tapped filament windings altogether. This is not advisable because of the variations in tubes with respect to the best adjustment of this potentiometer. This is especially true of detector tubes.

Some designers have used filter elements lavishly, in many cases actually introducing hum by improper placement of by-pass condensers or by use of improper circuits; others have succeeded in producing very quiet receivers with a smaller amount of hum-eliminating apparatus, and also without impairing the fidelity characteristic of the receiver as a whole.

III. Methods of Hum Analysis

Because of the very complex nature of the hum problems in electric receivers and of the fact that in the past they have concentrated their attention upon radio- and audio-frequency design, most engineers have not been able to give the proper amount of consideration to hum problems.

It would appear, therefore, that a proper method of analysis by which the various hum causes may be searched out, identified, and measured, would be of very real assistance to such engineers, as these hums must be segregated and understood before intelligent steps to eliminate or mitigate them can be taken.

Hum-Measurement Methods

To begin with, some form of equipment for measuring hum should be available. This is not nearly so easily realized as it might appear; since no particular method capable of yielding accurate results appears to have been generally adopted, a number of methods will therefore be described along with their advantages and limitations. It is hoped that a satisfactory scheme may grow out of one of these and become standardized.

The unaided ear, while a good comparison device, is quite unreliable otherwise, mainly because it provides no accurate indication or memory for amplitude, and yet in the end the ear is the sole judge of what constitutes a satisfactorily low hum level in receivers.

The audibility meter used with head phones is better, but those who have used this method will doubtless agree that it is neither reliable nor accurate.

It may be suggested that the unaided ear *is* a satisfactory means of measurement if the distance between listener and speaker be increased to the point where the sound is just over the audibility thresh-

old, and this distance itself or its squared value used as the intensity factor of the sound. In the first place, such a method requires either an absolutely quiet location or one with a small and constant amount of sound disturbance of uniform character or quality. In the second place, a location completely free from reflections must be used, as these set up stationary wave systems which hopelessly destroy the use of distance as the measure of intensity. Furthermore, because of the fact that all present speakers have great variations with respect to directional sound distribution from the theoretical point source, demanded by the classical inverse square law, further difficulties are noted. It is evident, therefore, that this method is beset by a great many difficulties. While the head phone and audibility meter method eliminates reflections, external noise to a great extent, and also directional effects, there are few who can get consistent results with it.

Microphone measuring apparatus will measure the amplitude of the air waves produced by the hum radiated from the loud speaker, but as we know, the ear responds to an energy factor proportional to the product of amplitude squared and frequency squared. Since the hum is usually a complex tone, the microphone method provides no satisfactory indication of the normal ear response to the sounds which it measures, inasmuch as the frequency factor is not accounted for in its measurement.

For the same reason a hum-voltage measurement across the loud-speaker terminals is not reliable. Here, in addition to the preceding difficulty, we have another in the fact that no speakers produce sounds over the complete hum-frequency range, whose amplitude bears a fixed ratio to the amplitude of the voltage across them. This, of course, could be overcome if the frequency characteristic of a given speaker were known. With the hum-voltage readings properly corrected by this speaker characteristic we would arrive at a measurement equivalent to that of the microphone method, but, of course, subject to the difficulties of the latter previously described. I have used this voltage measurement method to a considerable extent because of its simplicity, and I find it generally in use where any instrumental method is used at all, for with very good speakers the voltage readings follow with fair agreement the judgment of the ear as to loudness. However, with some speakers, a given adjustment, say of a filament potentiometer, will indicate more hum on the meter and less hum by the ear. This is usually due to deficient low-tone reproduction in this speaker. When this method is used, therefore, the results must be weighted by the pitch and audible intensity of the hum.

Another method is to substitute for the loud speaker a complex cir-

cuit to which the measuring vacuum-tubevoltmeter is connected, and which will so regulate the amplitudes of the various hum frequencies in a complex hum current that the meter reading will be corrected automatically for the frequency-response characteristics of speaker and ear. This corrected reading will provide a fairly true indication of the audible hum which that voltage would produce with a given speaker and normal ears. This, it appears, should be a rather good method.

Another method is to interpose a tunable circuit between the voltmeter and the speaker terminals so that the voltage at each particular frequency from 60 to say its 20th harmonic, or 1200 cycles, may be measured. These separate measurements may then be weighted in accordance with the combined frequency characteristic of speaker and ear and then added together to obtain a measure of the audible intensity produced by these voltages when acting on the ear through the transforming action of the speaker.

Another method of a similar nature is to make an oscillogram of the hum current, and by mathematical, graphical, or mechanical analysis to determine the frequencies and corresponding amplitudes of the various components. These may then be properly weighted and added together as above described, for obtaining the audible hum-producing intensity.

These last two methods are quite evidently too laborious for ordinary use, although giving prospect of reasonable accuracy.

There is still another method which appears to hold considerable promise. This was used by the writer in 1916 for making measurements of airplane noises while engaged by the Navy Department as expert radio aide for aviation at Pensacola, Florida. In this work I used a pair of radio head phones into which a 500-cycle signal current of known variable audibility could be sent. It was found that the signal current required in the telephones for audibility through the airplane noises was a very good measure of the noises themselves. It also served to indicate just what signal amplitude was necessary for satisfactory reception of signals through those noises under different conditions of flight.

I found that the signal audibility threshold, which was raised some times several hundred times the normal threshold value by the airplane noises, was much more sharply defined than when no external noises were present, so that more consistent and reliable measurements could be made. This method could very easily be adapted to hum measurements in radio sets. To do this an audio oscillator of known voltage output together with a potentiometer and watch-case receiver is necessary. The oscillator, say a 1,000-cycle device of the

type manufactured by the General Radio Co., which is itself rendered inaudible by suitable sound shielding, has its output connected across the ends of the potentiometer, the output of which is connected to the watch-case receiver. The receiver is mounted as near the humming speaker as possible. The potentiometer is then adjusted until the oscillator signal is just audible through the hum of the speaker. If the observer listens at a distance of about one foot while sound reflecting surfaces are kept at a distance large compared to this, standing waves due to reflections need cause no difficulty.

The voltage across the receiver as indicated by the potentiometer or as measured directly will then indicate the hum amplitude. This method is especially good because in the last analysis the ratio between signal and hum amplitudes in the receiver is of most importance, much as the static and signal levels are with static interference. If the measuring signal frequency lies in the neighborhood of the mean frequency of the program currents, for example, 500 to 1000 cycles, a very simple, easily operated, and satisfactorily accurate hum-measurement method is available.

Locating Hum Sources

One experienced in hum problems can usually, with the unaided ear and a few tests made without disturbing the circuit connections of the receiver, determine the cause of hum. Sometimes a mere listening test will disclose which of the three types of hum is predominant.

While the audible character of these hums cannot be described accurately, I believe anyone with normal ears can distinguish the low tone with a peculiar singing note added due to a wrongly adjusted potentiometer or to magnetic induction from the power transformer. In receivers with poor low-tone amplifiers only the peculiar singing sound, like the singing of telephone wires, may be heard; this is produced by higher harmonics of the 60-cycle current.

The smooth, sonorous, 120-cycle hum, due to insufficient current filtration, such as a baritone voice might emit in speaking the word *hum*, is also easily identified.

While not so often noticed, the "buzzy" type of hum is easily recognized too as originating in noisy detector tubes, of which it seems there are a great many, or in electrostatic induction from the rectifier and filter input elements. If you have ever had a wasp or bee buzzing at your ear you will have no difficulty in identifying this type.

In addition to these unaided ear tests a few circuit changes made externally with a short piece of wire are very helpful. For example, if the speaker or its input transformer be short circuited, any hum set

up in the speaker itself will remain alone; if the grid input to the second audio tube or tubes be shorted without disturbing the C bias, the addition of any hum by the output transformer, the second audio tubes, the current supply to grids or plates thereof, or off-set filament return, will appear, added to any hum already shown as caused by the loud speaker. If the grid input to the first audio tube be shorted, any induction hum entering the second audio transformer as well as any hum caused by the first audio tube or its grid or plate supply or its filament potentiometer, will appear added to those already noted in the other tests, if any there be.

When this short circuit is removed, the added hum due to the first audio transformer induction, detector tube or detector tube plate current, detector potentiometer, static induction to first audio grid, detector plate, or detector grid, will be added, and thus the entire audio hum of the receiver will be built up step by step. It may be noted, however, that in some receivers the hum decreases instead of increases, as the steps in this test are taken. This is due to what I have termed "inter-stage bucking," caused by the neutralization of one hum by another. This will be discussed more at length later.

Now if the detector grid leak be shorted, any static induction picked up on the grid side of this leak will be eliminated, and its effect on over-all hum noted.

Finally, if a strong unmodulated carrier is tuned in, any hum causes present in the r-f amplifier will bring in hum, caused by carrier modulation in the receiver. This may also increase or decrease the over-all hum of the receiver, depending on whether or not, after detection, the phase of the carrier modulation with respect to the audio hum of the receiver is zero or has some other value, and whether or not its wave form corresponds to that of the audio hum. It is possible to neutralize a strong audio hum by a strong carrier hum in this way if the circuit is properly arranged.

Complete Hum Analysis

While it is possible in a few minutes to locate fairly definitely the more usual hum sources in a receiver by the methods above outlined, nevertheless a complete, quantitative hum analysis will, in any case, be a valuable design aid, and sometimes a very necessary one. I have prepared a series of tests involving numerous circuit changes in the receiver, which, if carefully carried out, will serve to locate and measure practically all types of hum. Some suitable hum-measuring method should of course be available. These tests for the sake of simplicity are based on the use of an a-c vacuum-tube voltmeter connected across the input to the speaker.

The tests which follow are so arranged that the hum is measured in reverse order from output to input ends of the receiver.

Hum Tests

Speaker Hum. If the speaker is of electromagnetic or inductor type using permanent magnet field excitation, or electromagnetic excitation produced by ripple-free direct current, no hum will be developed in it unless it is located in some very powerful a-c field. The author has never noted such a case.

Dynamic speakers, however, almost always do develop hum to some degree, due especially to coupling between field and moving coils. To measure this, allow the field coil to receive its normal excitation, disconnect the input transformer primary from the receiver, and connect across it the measuring device and a load resistance equal to the plate impedance of the tube or tubes normally connected across it. Also substitute a dummy load resistance in place of the power tubes in the receiver, if the speaker field is energized from the set rectifier. If a power transformer or the input transformer, or any other a-c stray field device, is mounted on or near the speaker, these may be removed and then replaced separately for further analysis of the speaker hum.

Plate Ripple in Output Tubes. If the speaker has no measurable hum, it may be connected back in the receiver circuit and the hum meter connected directly across its input transformer primary, or across the speaker itself if no transformer be used; if the speaker hums, it is best to substitute an equivalent resistance across the tube output.

The filaments of the power tubes are excited by a battery and the grid circuit from grid to filament return point is opened. Then a "C" battery of correct voltage is inserted instead of the normal transformer secondary and grid-bias device. Thus only the plate-current ripple remains as a hum source, excluding induction sources, which are usually unimportant in this stage. This hum is then measured.

Filament Hum. The filament and mid-point return may then be tested for hum by removing the "A" battery and using the normal a-c excitation, substituting a "B" battery for the rectified plate current supply and leaving the grid battery in place. The dummy plate load of this tube should of course be used, but so connected that it does not enter the tube circuits.

Grid-Bias Ripple. The grid bias in the power stage may now be tested by taking off the grid battery and substituting the normal power supply bias with input transformer shorted, and reconnecting the "A" battery instead of the a-c filament supply. The "B" battery should be connected between the $B+$ point of the output circuit and the fila-

ment return, and a dummy load connected between the $B+$ point of the filter for the power stage and the filament return in this stage, so that the normal biasing voltage and ripple will be developed.

Power Tube Input Power Induction. If now with power tube operating entirely on direct current, and the filter connected to a dummy load instead of to the tube, the primary circuit of the power tube input transformer be opened, and shunted by a resistance equal to the plate impedance of the first audio tube, any magnetic induction into this transformer, or any static induction to the second audio tube, may be measured.

Ordinarily this is negligible, but may be considerable in special cases.

First Audio Plate Ripple, Grid Ripple, and Filament Hum. These are measured as previously described for the power tube by the use of d-c filament, plate and grid batteries.

First Audio Input Induction. This also is measured in the manner already described for the power tube, that is, with power and first audio filament, plate and grid voltages obtained from batteries, and the first audio transformer shunted by a resistance equal to the detector tube plate resistance. If magnetic or static induction is present, this may now be measured. If it is magnetic in character, this may be determined by unmounting the transformer, and removing it to a distance, or orienting or preferably both, to determine the source of induction; if it is static induction, this may be determined, although not so easily, by placing the first audio tube in a separate unmounted socket properly connected and moving both tube and transformer away from the high a-c or pulsating sources. Magnetic induction into the tube itself may also be determined by this test if a certain amount of good judgment be used in analyzing the results.

Plate, Grid, or Filament Hum of Detector Tube. These may be measured by employing again the same general methods above described for the first audio and power stages, except, of course, that if grid detection be used, no "C" battery is necessary, the grid leak being shorted instead.

Modulation. To measure modulation hum, operate detector and audio amplifier wholly on batteries, remembering as before to substitute dummy loads for tubes where these are removed from the power-supply circuits. Then tune in a strong unmodulated carrier, preferably from a battery-operated signal generator, of say 10,000 μv per meter. Any modulating influences, such as plate ripple, grid ripple, or tube modulation, produced by internal or external causes, will set up a hum the cause of which can be found as before, by the sub-

stitution of batteries, or by moving suspected external sources of magnetic induction into the tubes themselves, such as power transformer or filter choke.

While it is possible to suggest alterations or to elaborate still further upon this suggested procedure, I believe a sufficiently complete idea of the general method has been given, so that the various causes of hum may be tracked down and isolated by this process of elimination. As before stated, the first step in hum elimination is to determine its cause; then, ordinarily, remedies will suggest themselves.

IV. Receiver Design for Hum Elimination

Minimizing Induction Hum Effects

The hums caused by induction require very great care in elimination, particularly in receivers with high-quality amplifiers, where available space is limited. When extremely compact designs are required, the designer invariably experiences difficulty with induction.

It is not my intention here to develop complete designs; but I will present some of the more important design methods that my experience has shown to be of value.

The preceding discussion has indicated that it is advisable to allow plenty of distance between the sources of inductive disturbances and those parts of the receiver most sensitive to them. In compact receivers the magnitude of the effects is much greater and therefore requires much more careful design and workmanship. For example, a first audio transformer when mounted within a few inches of the power transformer or first filter choke may cause little or no hum if both power transformer and audio transformer are located in precisely the correct locations and properly oriented. However, a displacement of a small fraction of an inch of either may destroy the condition of minimum coupling and cause a really objectionable hum to be picked up.

One method of reducing this induction in compact designs is to house the emitting source or the receiving device or both in suitable shields to confine the stray fields. Ordinary sheet iron such as that used for transformer housings, while perfectly satisfactory for electrostatic shielding, is of small effectiveness for magnetic shielding. A high grade of magnetic iron or steel, such as pure soft iron, or the usual magnetic steels, is much superior; while more expensive, the very high permeability alloys such as permalloy and others are by far the most satisfactory. Since it is difficult to predict the direction of minimum induction from a given source of stray magnetic fields, owing to the distorting

action of the steel chassis or of other neighboring magnetic bodies, the exact locations of power transformers, chokes, and audio transformers can hardly be predicted from theoretical considerations alone. The placement therefore is best determined experimentally.

Although, as before mentioned, the first audio transformer is ordinarily the most sensitive part of the receiver to the stray magnetic fields, the second transformer as well as the tubes must be given due consideration also.

Electrostatic Fields

As before pointed out, these portions of the circuit and apparatus carrying high alternating or pulsating potentials above ground must either be statically shielded or removed to a safe distance from the sensitive input parts of the audio amplifier. The sensitivity of these points is in the following order: detector grid input, if grid-leak detection be used, detector plate, first audio grid, first audio plate, and so forth.

The most troublesome sources of this induction are again, in order of amplitude, rectifier and filter input elements and wiring, primary circuit of power transformer, such as switch leads or connecting cord, and intermediate or output elements of the filter. To reduce or eliminate these fields as hum sources, it may be sufficient in designs with plenty of room to choose properly the locations of hum sources and hum-receiving devices or wiring. In compact designs complete electrostatic shielding of the sources or of the receiving devices or both may be necessary.

Where leads with high a-c potentials must pass near the sensitive points the induction may be eliminated by the use of shielded leads with shield grounded. Shields in the power transformer are also effective. While a shield between the primary and all the secondaries is common and effective in reducing both audio- and radio-frequency disturbances originating in the power line, another between the rectifier windings and the filament secondaries is also helpful. Shield cans around the detector or first audio tubes are also sometimes useful.

Since the detector grid and input leads, including grid leak and condenser, are especially susceptible to statically induced hum, these should be mounted as close to the chassis as possible or near some other parts of the receiver or wires at or near ground potential. The easiest method is to connect leak and condenser directly to the grid terminal of the detector socket and close to the metal chassis.

If the detector plate lead to the first audio transformer be long or cabled, as it often is, with other leads carrying high or moderate

a-c potentials, the resulting induction can be eliminated by using shielded cable for this lead or for the offending source lead.

These are the more important design aids useful in the development of hum-free receivers with respect to induction hum.

When a hum persistently refuses to respond to any of these treatments, it may sometimes be neutralized by opposing magnetic or electrostatic couplings suitably chosen and adjusted.

Filter and Receiver Design For Minimizing Hum Due to Ripple and Plate Supply to Tubes

The writer has for a number of years given a great amount of thought and study to the development of new methods of hum elimination capable of reliable performance with very small amounts and costs of filter apparatus. Some of these will now be described; others must be reserved for some future time.

The filters generally used in the past few years have been chiefly what is usually designated as the "brute force" type. They receive the

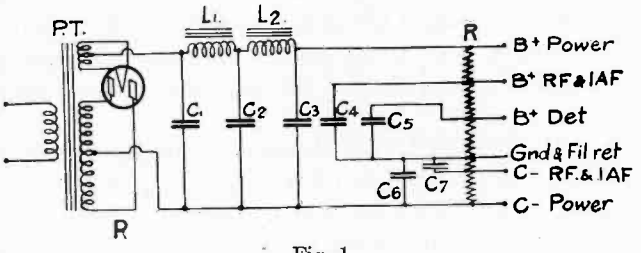

Fig. 1

rectified current and deliver to output terminals a substantially ripple-free direct current. Across the output terminals a voltage-dividing resistance is connected from which the various voltages of the receiver tubes are obtained by means of suitable taps. Such a system is shown in Fig. 1.

Here is shown the power transformer PT, full-wave rectifier tube R and the familiar two-stage filter, consisting of chokes $L1$ and $L2$ and condensers $C1$, $C2$ and $C3$. Across the filter output, that is, across $C3$, is connected the tapped resistor R, from which the several "B" and "C" voltages are obtained for the receiver. The condensers $C4$, $C5$, $C6$, and $C7$ are provided rather more for signal by-passes than for hum reduction. Without these, very strong interstage couplings in the receiver may be obtained which cause motor-boating or other oscillations, or degenerative effects on the desired signal. This circuit is typical of the now obsolete battery eliminators of several years ago,

but is still to be found in a number of otherwise modern receivers. It requires, ordinarily, two rather large chokes and capacity to the total amount of 15 to 30 or more μf.

While such a circuit can be made quite effective, if sufficient inductance and capacity be used, it is an expensive and inefficient system. You will note that the current supply for the power tube is filtered just as well as that for the first audio, radio, or dectector tubes, notwithstanding the fact that the detector tube plate ripple, for example, may be amplified as much as 500-fold into the plate or output circuit of the power tube. If the detector plate current is sufficiently filtered to prevent hum in the speaker connected to the power tube, after all of this amplification, then the plate current of the power tube, with no succeeding amplification, has been filtered 500 times too well.

The logical arrangement, then, is to proportion the filtering for the different tubes in such a way that the current supply to any tube is no better than necessary. The power tube current requires relatively little filtering, the first audio and radio tubes more, and the detector tube most. That is to say, if the power tube hum will permit of a one per cent plate ripple, that of the first audio must be reduced to the order of 0.04 per cent, and that of the detector to the order of 0.002 per cent.

Because of the possibility of interstage couplings in the receiver, due to portions of the voltage dividing resistance being included alike in grid and plate circuits of tubes, with large intervening amplification, the by-pass condenser shown must be rather large. This is especially important with respect to *C*6 and *C*7, the grid by-pass condensers, because the resistances across which they are bridged are small.

It is also to be noted that the resistance as connected across the filter output causes a loss of the rectified and filtered current, which performs no other really useful function than to generate unwanted heat. It may be argued that if all of the receiver tubes except the rectifier be removed, the filter condensers will be subjected to higher voltages, which this resistance helps to hold down by its loading effect. While this argument may have some validity for separate battery eliminators, in my opinion it has no validity in present-day receiver designs, inasmuch as intelligent users will not operate their receivers with all the tubes removed, especially if instructed not to do so. Furthermore, unless the wasted current in this resistance is a very considerable portion of the total filter load current its effectiveness as a voltage limiter may be small; and if the filter condensers have an otherwise satisfactory voltage rating they will certainly withstand

any temporary rise of voltage caused by the removal of one or more, or even all, of the receiver tubes. As we all know, these condensers are factory tested at voltages many times their rated voltage for continuous service.

The current wasted by the resistor is not the worst of its offenses. By increasing the load on the filter, it increases the ripple component of the filter output impressed upon the tubes of the receiver and thereby makes necessary the use of increased filter elements.

The manner in which the ripple varies with the load current of a simple condenser type of filter, for varying capacities, is shown graphically in Fig. 2. The circuit diagram indicates the test arrangement.

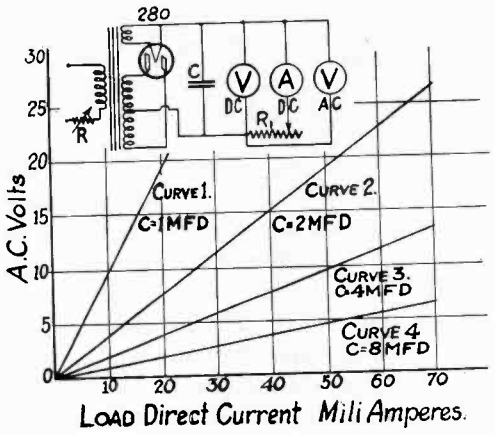

Fig. 2

By means of resistors R and $R1$, the load current was varied at a constant load voltage of 250 volts, through the usual range up to 70 ma. Curves 1, 2, 3, and 4 indicate the variation of a-c ripple in volts present across the load with 1, 2, 4, and 8 μf of condenser, respectively. It is seen that with any given amount of condenser, the ripple voltage varies directly with the load current. The familiar law of diminishing returns noticed by most engineers engaged on filter designs is here clearly shown. With one μf in circuit, the addition of another causes about a 50 per cent decrease in ripple, while the addition of three more only reduces it to about 25 per cent, and the addition of seven more only reduces it to about 10 per cent. These graphs make clear that all unnecessary loads on the filter should be dispensed with. Doubling the load, for example, requires double the amount of filter apparatus for the same ripple magnitude.

The resistance, of course, also adds additional load on the rectifier

tube tending to reduce its life, makes necessary a larger power transformer, and causes a greater current consumption from the line by the receiver, not forgetting the cabinet warping effects of the liberated heat.

The voltage-dividing resistor is seen therefore to be an expensive element in receiver design.

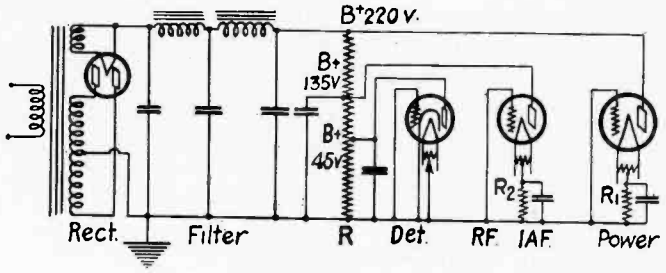

Fig. 3

Some manufacturers still use the tap resistor across the filter output as a "B" voltage divider only, the two grid voltages being obtained from bias resistors receiving the plate currents of power tube and r-f and first audio tubes. This now more generally used arrangement is shown in Fig. 3. Here *R* is the plate voltage divider, *R*1 is the power-tube grid-bias resistor, and *R*2 is the bias resistor for first audio and all radio tubes. To prevent circuit complication the coupling devices have been omitted from this diagram. While greatly reducing the possibility of interstage couplings, this arrangement still has most of the disadvantages of the preceding system.

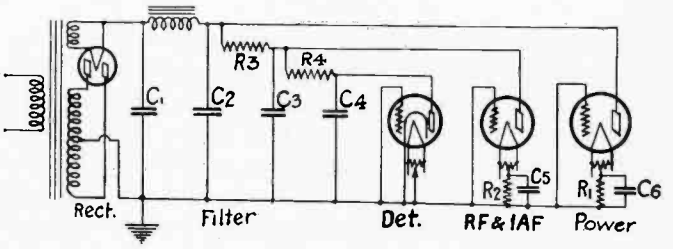

Fig. 4

A much better circuit arrangement is shown in Fig. 4. Here a series filter arrangement is shown which provides one stage of filtering for the power tube, two stages for the first audio and all radio tubes, and three stages for the detector tube. While choke coils may be used for the intermediate and detector filters, ordinarily the resistance values necessary for proper voltage reduction, when used with capacities of

1 or 2 μf, provide sufficient additional filtering for the intermediate and detector tube currents.

It will be noted that this circuit eliminates all loss current, provides proper voltages for all tubes, regulates the filtering for given tubes to a degree determined by succeeding application, and eliminates the couplings between grid and plate circuits of different tubes previously noted.

With a circuit of this type it is ordinarily possible to produce better results with about one-third the amount of filter apparatus required by the first type, and with about one-half the amount required by the second.

Interstage Hum Bucking

If this last arrangement has filter elements so proportioned that hums from all tubes due to filter ripple are equally low and unobjectionable in a loud speaker, we may proceed further to reduce the required amount of apparatus. This may be accomplished by reducing inductance or capacity in the first filter section so that the power tube develops a hum having a magnitude five or ten times the tolerable limit, that is to say, about 1 volt, if the predominant frequency as usual is 120 cycles. This is done also in the second filter stage, feeding the first audio tube, so that this produces a 1-volt hum in the plate circuit of the power tube. If now the phases of these two hums be reversed 180 deg. in the plate circuit of the power tube, by properly poling the second audio primary, and by regulating the resistance $R3$ and condenser $C3$, Fig. 4, these two hums may be neutralized. I call this type of neutralization "interstage hum bucking."

Hum may likewise be introduced in the detector stage by filter reduction, and neutralized either in the second audio or power stages; or it may be added to or substracted from the first audio hum and the residual neutralized in the power stage.

If, as is usual, the radio tubes obtain their grid and plate voltages from the same points supplying the first audio tube, the best plan is to provide sufficient filter apparatus in the second filter stage to prevent the introduction of hum by all of these tubes, and then to neutralize the power stage hum by that of the detector stage. Otherwise modulation hum may appear.

A pure audio hum without r-f carrier can also be neutralized by carrier modulation, caused by insufficient filtration of the radio tube current. In this case the receiver may possess a strong hum when no carrier is received, which will disappear when a carrier, whether modulated or unmodulated, at the transmitter is tuned in. The disadvantage of this scheme is that unless the audio hum be adjustable,

the neutralization is complete only when the carrier input to the detector tube has a particular amplitude. This, as before mentioned, results from the fact that the carrier modulation amplitude is governed both by the receiver modulating influence and by the strength of the carrier in the receiver itself.

Another form of interstage bucking occurs in most receivers with one or more filament potentiometers. Assume that fixed mid-point potentiometers or filament windings are used for power tube and first audio and r-f tubes, and that an adjustable potentiometer is used for the detector heater. It is observed that a fixed mid-tap will provide minimum hum with only a small proportion of tubes, so that for most tubes it is somewhat out of adjustment, thus causing a 60-cycle voltage to be introduced in the grid of the particular tube or tubes which it serves. An adjustable detector heater circuit mid-tap may be made to neutralize the hum so introduced by setting up the same type of hum

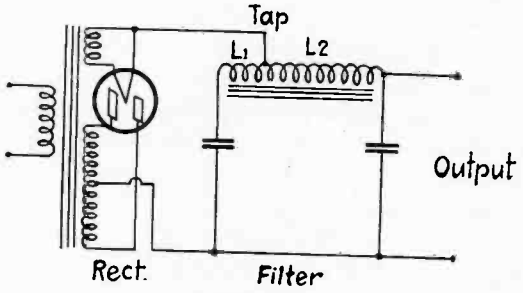

Fig. 5

in the detector stage. This when amplified into the grid circuit of the first audio tube will, if correct in phase, wave form, and amplitude, neutralize the first-mentioned hum. The detector hum phase may be selected and its amplitude regulated merely by adjustment of this detector potentiometer. The same effect may be secured by using the adjustable potentiometer in the first audio stage instead of the detector. 60-cycle induction or "B" ripple hums can also be neutralized to some extent in this manner.

Tapped Choke Filter

Another method of considerably increasing the effectiveness of a given amount of filter apparatus, or of reducing the amount of apparatus required for a given output ripple, is what I call a "tapped choke filter." This circuit is illustrated in Fig. 5. Here the rectifier is connected to the filter choke at some point near one end, the filter condensers being connected to the ends of the choke winding. An in-

put condenser may also be connected across the rectifier if desired. This circuit ordinarily will reduce the ripple output by a factor of five to ten over that obtained with the same choke and condensers connected in the usual manner. Or, conversely, it will provide just as good a filter with considerably smaller values of the filter elements.

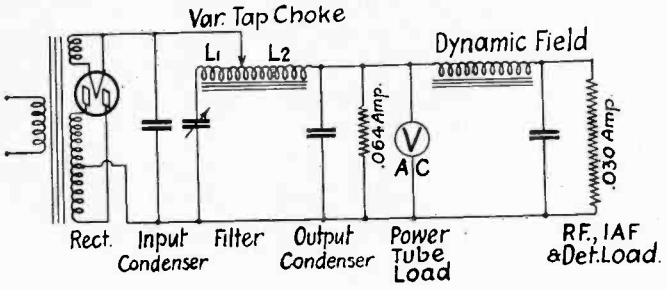

Fig. 6

The increased filter action is due to the neutralizing effect between the a-c components of the two portions of the choke. That is, a rather strong a-c component flows through the portion marked $L1$, the coup-

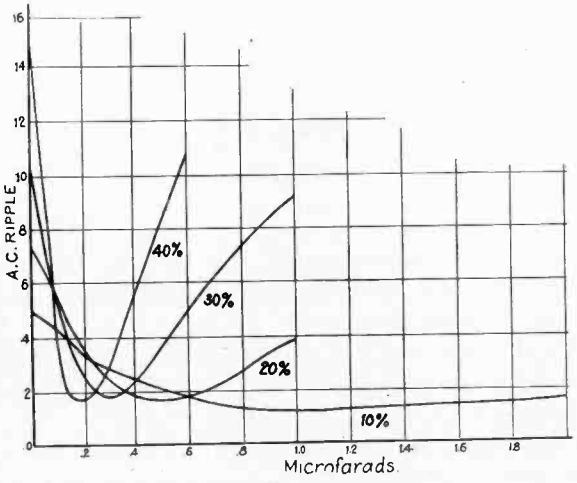

Fig. 7

ling of which to $L2$ neutralizes to a large degree the alternating voltage component therein, so that the output a-c component is reduced.

Some curves showing the performance of this circuit will now be shown. These curves were made by Arthur B. McCullah, of the Gulbransen Radio Co. of Chicago, and are here included by his kind permission. The circuit arrangement used is shown in Fig. 6. It will

be noted that an input condenser was connected directly across the rectifier, that the vacuum-tube voltmeter for measuring the filter ripple was connected across the power-tube load, and that the direct current in the filter was 94 ma. You will note further that the condenser connected to the left end of the choke is variable.

Fig. 7 shows, for several tap points on the choke coil, the effect of changing the variable condenser. The per cent designations refer to the percentage of total turns in the input side of the choke coil. The ordinates are arbitrary measures of ripple and the abscissas are capacities of the variable condenser in μf.

It will be noted that while low ripple levels may be obtained with capacities as low as 2 or 3 tenths of a μf, not much variation from the best value can be tolerated without increasing the ripple.

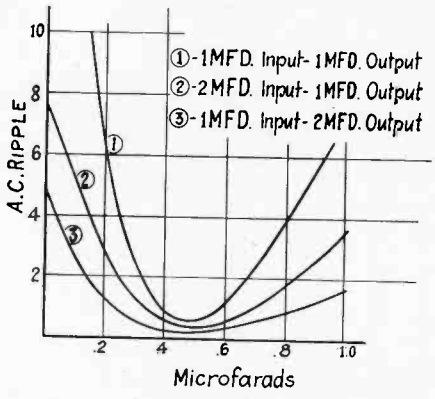

Fig. 8

As the tap percentage increases, the capacity increases and becomes much less critical. A 20 per cent tap appears to be quite effective without critical condenser value.

In Fig. 8 is shown a family of curves indicating that the adjustment of the neutralizing condenser is not affected by change of input or output capacities.

Further tests have shown that if the full choke coil is used in a normal filter circuit, more than twice as much filter capacity is required to reduce the ripple to a given level.

This type of filter stage may of course be used singly or in series with others of the same or of different types. If the condenser across the rectifier is omitted, an additional advantage is obtained in that the rectifier load due to such a condenser is greatly reduced and the rectifier tube life prolonged. In a particular very popular receiver using a 2-μf condenser in this position and having a filter output direct cur-

rent of 70 ma the alternating current through this input condenser was also 70 ma, thus increasing the load on the rectifier tube. Another valuable advantage of the tap choke filter is therefore evident. I have developed many modifications of this arrangement wherein choke coils of successive filter stages are coupled for hum reduction; also wherein filter chokes are coupled to audio transformers or to other audio-frequency coupling devices for the same purpose, and having the same general defect.

Neutralization by Hum Feedback

Another method of hum neutralization which I term "hum feedback" is capable of very surprising results. It is not used in the filter, but in the receiver circuit. The circuit arrangement as applied to a single tube or group of tubes obtaining plate and grid-bias voltages from the same points, such as the first audio and all-radio tubes as a group, is shown in Fig. 9.

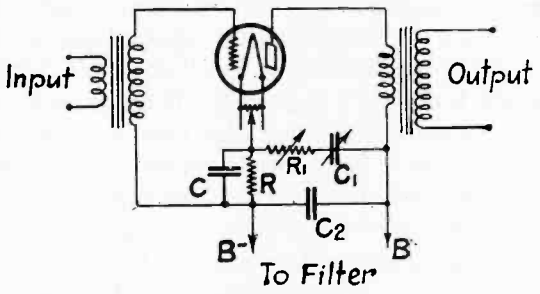

Fig. 9]

Here a tube is shown with input and output coupling devices, "B" voltage being obtained from the receiver filter output, and "C" voltage from the voltage drop produced across the grid-bias resistance *R* by the plate current of the tube. A condenser *C* is connected across this resistance for signal by-pass, first to keep this resistance out of the signal output circuit, and secondly to prevent the signal voltage-drop across it from introducing degenerative effects in the grid circuit of the tube. Condenser *C*2 is the normal combined filter and filter by-pass condenser. So far this is a normal and now well-known circuit. If a strong ripple component is present across the "B" current input, that is, across *C*2, this ripple voltage will drive a corresponding ripple current through the tube superposed on the direct current driven through it by the direct voltage. This a-c component will develop a corresponding alternating voltage across the secondary of the output transformer, which will ultimately appear in the follow-

ing reproducer as a loud hum. If the tube be used for radio-frequency amplification, the carrier will be modulated, and after detection and amplification, the hum will likewise appear.

If now condenser $C1$ and resistance $R1$ be connected and properly adjusted, the hum will completely disappear without harming the normal signal amplification of this amplifier stage; as a matter of fact it will actually be improved, because the plate circuit signal current will have another path from output transformer $B+$ to tube filament in parallel with that already provided through $C2$ in series with C and R in parallel. Furthermore, the signal thus by-passed through $C1$ $R1$ cannot cause a degenerative effect because it does not flow through R and C, as does that portion flowing through $C2$. The action of this circuit is as follows: A path for the a-c component only of the "B" current is provided across B+ B− through $C1$, $R1$, and thence through C and R in parallel. Since C and R are included in the grid circuit of the tube, the a-c ripple thus developed will produce a ripple voltage of a magnitude, phase, and wave form determined by $C1$, $R1$, R, C, and the corresponding characteristics of the ripple voltage across $B+$ $B-$. When $C1$, $R1$, R and C are properly chosen, the neutralization is of a very high order. It will be seen that the effect of $C1$ $R1$ is to introduce into the grid circuit of the tube a ripple voltage of the same wave form but of opposite phase, and having an amplitude less than that of the plate-ripple voltage by a factor equal to the amplification factor of the tube. Both grid and plate therefore have the alternating ripple voltages applied, but these are neutralized at every instant, so that no alternating current can flow through the tube because of them, and only the direct component of the grid and plate voltages remains effective to permit current to flow. Since the signal input voltage is applied to the grid alone, it can and does produce a corresponding alternating signal current component in the plate circuit, which appears in the output for further amplification, for speaker operation, or for any other desired function.

Some curves showing the performance of this arrangement may be of interest, the data for which were obtained with the circuit arrangement shown in Fig. 10.

A 280 full-wave rectifier tube is shown normally energized by a power transformer. It operates into a single stage filter consisting of a 1/2-μf condenser $C1$, a choke coil L, having an impedance of 23,600 ohms at 120 cycles and 31 ma of direct current, followed by a 1-μf condenser.

A d-c milliammeter is included in the filter line to the load, which consists of the load resistance R and the 171 power tube shown. The

load current was 31 ma. A d-c voltmeter across the load resistance indicated the d-c voltage which was 220 volts. The 171 tube has no signal input but was provided with a proper output transformer connected to a Western Electric 540-AW speaker, and a vacuum-tube voltmeter as shown. The grid-bias resistance was 2,250 ohms, and its by-pass condenser $C3$ was 1 μf. An adjustable mid-point potentiometer was

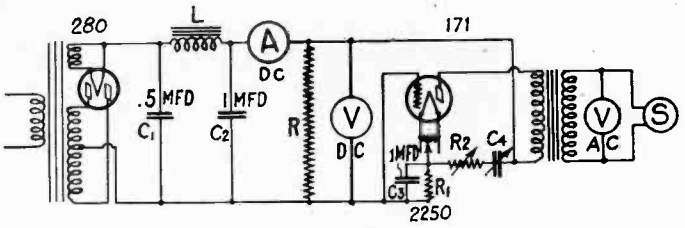

Fig. 10

included and carefully adjusted for minimum hum. The hum feed-back condenser $C+$, and resistance, $R2$, were both variable.

In Fig. 11 the curve marked "Hum" with ordinates at the left in volts indicates the variation of hum output with simultaneous variation of the hum feed-back elements $C4$ and $R2$. Variation of $R2$ is indicated in the curve labeled $R2$, whose ordinate scale in ohms is at the right.

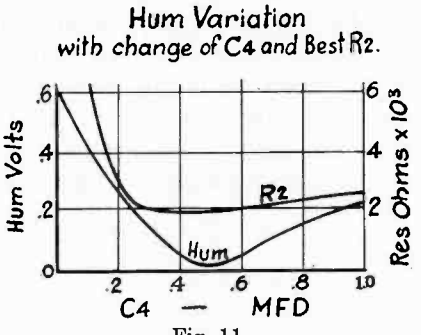

Fig. 11

The abscissa scale is in μf of capacity of the variable condenser $C4$. For any given point on the hum curve, the capacity of $C4$ is given by the abscissa corresponding to the ordinate of this point. The resistance value for this hum point is obtained from the intersection of the ordinate with the resistance curve. Thus, for 3/10 μf and 2,000 ohms, the hum voltage is 0.16 volt or 160 mv. The un-neutralized hum, that is, the hum with $C4$ equal to zero, is 600 mv, while the least hum, obtained with 1/2 μf and 1900 ohms, was only 10 mv. This

residual hum was caused almost altogether by the a-c filament excitation of the tube.

In Fig. 12 the curve marked $R2$ represents the hum variation with variation of $R2$ alone, $C4$ being fixed at $1/2\,\mu f$; in the curve marked $C4$ I show the variation of hum with variation of $C4$, the resistance being fixed at 1900 ohms. The abscissas of curve $C4$ indicate tenths of a μf, while for $R2$ they indicate thousands of ohms. These two curves

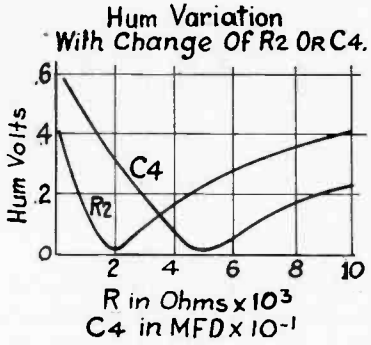

Fig. 12

show the resistance and condenser tolerances with the neutralizing factor here indicated, which is about 60.

This circuit may be used with equal advantage in audio- or radio-frequency amplifier tube circuits. I have with some forms of it obtained neutralizing factors as high as 10,000. That is to say, an output hum of say 50,000 mv could be reduced to one of about 5 mv when the circuit constants were carefully adjusted. I have developed many variations of the hum eliminating methods heretofore described, and many other methods, the presentation of which must be reserved for some future time.

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SOME POSSIBILITIES OF INTELLIGENCE TRANSMISSION WHEN USING A LIMITED BAND OF FREQUENCIES*

By

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Summary—*As an ideal lower limit, certain possible methods of radiotelegraph transmission may require only a single side band of 25 cycles for each 100 words transmitted per minute, so that each average present-day short-wave channel provides enormous potential facilities for radiotelegraph transmission. Neglecting the requirements for the separation of channels to avoid interference, the maximum potential traffic capacity of the entire short-wave spectrum down to 10 meters is something like 500,000 stations, each transmitting at 100 words per minute and using a double side band. This figure does not take into account the possibilities of directional transmission, and assumes each station has worldwide range. The problem of utilizing these possibilities is economic and broadly political as well as technical; engineering methods can be developed more highly than at present, whenever the economic value of the new channels created is sufficient to pay the cost.*

The ultimate capacity of the broadcast band may approach one program per three channels for every listener. If synchronizing proves to be successful, by giving each broadcast chain a band of frequencies about 30 kc wide and requiring that the stations of the chain be divided into three groups, with each group operating on a different common frequency within the 30-kc band, the amount of broadcasting made available to the public may be enormously increased. Thus 30 chains averaging 100 stations each might put 30 programs within reach of practically every listener in the country, and would, under certain ideal assumptions, permit the simultaneous operation of 3000 "super power" broadcast stations. The ultimate problem of broadcasting may be to find enough stations to fill up the chains, instead of restricting the number as at present.

The real future of television probably lies in transmission over wires rather than radio. This is because the wide frequency band required for television having entertainment value can give more public service when put to other uses.

Progress can be made in building up a radio structure that will give the maximum of service to the public, by the encouragement of developments which may enable chain programs to be broadcast by groups of stations operating on synchronized carrier waves, and by the proper assignment of channels for radiotelegraph transmission.

THE increasing use of radio communication has served to emphasize the fact that there is a limit to the facilities of this type which nature has supplied. It is felt by many that we are now approaching the limit of our radio resources, and that after stations are operating on all the channels now being rapidly assigned, the future of radio transmission will be primarily in operating these sending sets.

* Dewey decimal classification: R190. Presented before San Francisco Section of the Institute, March 20, 1929.

It is the purpose of this discussion to evaluate the intelligence-carrying possibilities of our radio facilities, to point out what can and what cannot be expected from radio in the future, and to indicate in a general way some of the ultimate possibilities of radio communication. Emphasis is intentionally placed on certain rather ideal considerations, and only incidental discussion is given of the apparatus limitations involved or possible ways of designing equipment to utilize the narrow band widths which are otherwise seen to be theoretically possible.

Frequency Bands Required for Different Classes of Transmission

Intelligence may be transmitted by telegraph, telephone, still pictures, or moving pictures. Each of these methods requires the use of a band of radio frequencies having a width determined by the following principles:

Telephone. A single side band 5000 cycles to perhaps 15,000 cycles wide is required for the transmission of speech and music of high quality, the greater band width being required as the standard of quality becomes higher. Understandable speech requires all voice frequencies from about 250 cycles to 2750 cycles, a side band 2500 cycles wide.

Telegraph. The side band required to operate an ordinary telegraph relay or printer at the receiver has been determined by engineers interested in submarine cable telegraphy, and is slightly under 2.0 times the dot frequency of the signal.[1,2] The transmission of 1000 letters of ordinary English per minute by the Continental Morse code requires 4762 dot frequency cycles per min.[3], or a side band of approximately 131 cycles when the received signal is to actuate a relay. With a five-element two-valued code of the type employed on multiplex printing telegraph systems a transmission speed of 1000 letters per min. (200 words

[1] The dot frequency is the number of dots per second when a continuous stream of dots is being transmitted.

[2] The exact figure that should be used is somewhat uncertain. Milnor, in "Submarine cable telegraphy," *Trans. A.I.E.E.*, 41, 20, 1922, states that satisfactory tape records are obtained when frequencies up to 1.5 times the dot frequency are preserved, and that satisfactory relay operation is obtained when frequencies up to 1.65 times the dot frequency are present. Curtis, in "The application of vacuum-tube amplifiers to submarine cables," *Bell Sys. Tech. Jour.*, 6, 425; July 1927, states that the receiver amplifiers used in the permalloy loaded transoceanic telegraph cables give an amplification that decreases from a high value at 1.5 times the dot frequency to practically zero at twice the dot frequency.

In the remainder of this paper it will be assumed that telegraph communication requires the transmission of frequencies up to 2.0 times the dot frequency. This figure is probably somewhat in excess of the actual minimum required, and can therefore be considered as including the narrow band of unused frequencies which must be present to separate adjacent channels.

[3] Frederick Emmons Terman, "Note on the effective heating of code transmitters," Proc. I.R.E., 16, 802; June, 1928.

per min.) is obtainable when using a side band only 100 cycles wide.[4] By employing a synchronous vibrating relay to restore the shape of the received multiplex code signals it is possible to cut this frequency band in half,[5] *thus permitting transmission at 200 words per minute using a side band of only 50 cycles and giving perfectly shaped received signals.* Such a narrow frequency band may seem fantastic to many radio people, but years of submarine cable practice have shown it to be commercially practicable in that service.

Picture Transmission. The side band required in picture transmission is proportional to the area of picture transmitted per sec., and the number of picture elements per square inch. The minimum side band that will carry the picture is one-half of the number of picture elements transmitted per sec.,[6] and this is sufficient only when all phase and attenuation distortion is corrected. It therefore requires a side band at least 1800 cycles wide to transmit 1 sq. in. of 60-line per inch picture per sec. under the most favorable conditions.[7]

Television. Television is merely picture transmission speeded up, but as each individual picture need not have a quality equal to that required of a still picture, television transmission can use fewer lines per inch in the picture, and can use a lower frequency band in proportion to the area of the picture. A good quality 50-line picture 1 in. square, when repeated 16 times per sec., requires a side band of about 15,000 cycles per second when all phase and attenuation distortion has been corrected,[8] and perhaps several times this value with ordinary uncorrected communication circuits.

[4] This figure is determined by the fact that such a code has 2½-dot cycles per letter, and assumes 5 letters per word.

[5] A. A. Clokey, "Automatic printing equipment for long loaded submarine telegraph cables," *Bell Sys. Tech. Jour.*, 6, 402; July, 1927. Some question might be raised as to whether it is possible to realize this halving of the frequency band in the case of radio. A study of the situation shows, however, that the synchronous vibrating relay can be applied to radio signals by introducing some minor and rather obvious modifications. It is to be understood that in making this statement the writer realizes the present economic situation is such that there is nothing to be gained by using such a relay, but at the same time, in evaluating the *possibilities* of radio communication, the synchronous relay must be taken into account.

[6] Frank Gray, J. W. Horton, and R. C. Mathes, "The production and utilization of television signals," *Bell Sys. Tech. Jour.*, 6, 560; October, 1927.

[7] In present practice a wider frequency band is required. Thus in "Transmission of pictures over telephone lines," by Ives, Horton, Parker, and Clark, *Bell Sys. Tech. Jour.*, 4, 187; April, 1925, it states that 5 sq. in. of 100-line picture are transmitted per minute using a double side band 1900 cycles wide. This corresponds to a side band about twice as wide as the minimum possible value.

Captain Ranger has stated that in the R.C.A. system of picture transmission it is desirable to preserve up to the third harmonic of the picture element frequency when using transmission circuits involving radio links. This gives a side band requirement of six times the minimum possible value.

[8] On the basis of one-half the number of picture elements per second, this

The Present Situation

The existing radio structure utilizes the useful radio frequencies very inefficiently as considered in the light of future possibilities, particularly in high-frequency transmission, and in the case of telegraph communication. The high-frequency channels now assigned by the Federal Radio Commission are separated 0.2 per cent, this value being fixed by the frequency stability that can be maintained with certainty. A telegraph station operating at a frequency of 10,000 kc is accordingly assigned a frequency band 20,000 cycles wide in order to carry on a transmission that at 100 words per minute requires, as an ideal limit, only a single side band 25 cycles in width. Even the present broadcast band from 550 to 1500 kc could give much more public service than it now does. The spectacle of 50 radio stations broadcasting the same chain program on 50 different frequencies may some day be recognized as one of great economic loss, and may ultimately be replaced by 30 to 40 chain programs, each one of which could be broadcast by 50 to 100 stations using 2 to 3 channels per program. With accurately maintained frequency stabilization, it would undoubtedly be possible to operate widely separated telephone transmitters on carrier waves separated in the neighborhood of 8 in place of the present 10 kc with a corresponding increase in the number of channels, although this would result in a loss of fidelity of transmission as compared with that obtainable with the 10-kc separation.

The Economic Balance Between Types of Service

In the radio structure of the future it is almost axiomatic that every useful radio channel will be worked to the limit, and that the present inefficient situation is merely temporary. The change that is bound to take place will very profoundly alter the economic balance between types of service. At the present time, with 0.1 per cent frequency stability, neglecting the possibilities of directional transmission, two adjacent 20-kc channels in the vicinity of 10,000 kc provide double side-band transmission facilities for two telegraph stations, or for two telephone stations, or for the transmission of something less than 2 sq. in. of 100-line picture per sec. or a fair television image less than 1 in. square. When every cycle is used to the very limit, these same two channels may be used to give double side-band transmission of a fair television picture about one inch square, or of something less

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figure would be 20,000, but the work of the Bell Laboratories indicates that the band may be reduced to 15,000 cycles without introducing more than barely detectable distortion in the image. This 25 per cent reduction is possible because the picture is moving.

than four square inches of 100 line picture per sec., or assuming perhaps rather extreme developments in the sharpness of cutoff of transmitters and the selectivity of receivers, four broadcast programs *or an ideal maximum of 400 radiotelegraph transmitting stations each operating at a speed of 200 words per min.*

It is apparent that the tremendous economic value which a narrow frequency band has, when devoted to message transmission, will cause most of the radio facilities to be ultimately devoted to telegraph or telephone communication, and that television will be relegated to an insignificant place. To have real entertainment value a single moving picture will require a frequency band that would displace some thousands of telegraph stations. Television signals will undoubtedly have some place in the radio structure, but their most promising method of dissemination appears to be over wire circuits. It is to be expected that broadcasting stations will be able to hold their own in competition with the pressure from telegraph services because each broadcast station requires a single side band only 5000 to 15000 cycles wide in order to give entertainment to hundreds of thousands of listeners.

The Effective Utilization of the Broadcast Band

The fundamental fact that must be considered in the broadcast band is that there are many more people and organizations that want to broadcast and that have the financial resources to do so than there are channels to accommodate their stations. Improved methods of controlling the frequency of the radiated carrier wave might, except for the increasing requirement for higher quality of transmission, be expected to permit a small reduction, in the width of each channel, and will sometimes make it possible to operate distant stations on the same channel with unsynchronized carrier waves without objectional heterodyning. At best, however, these developments are only palliatives.

The real solution of the broadcast situation lies in the development of some form of chain broadcasting on synchronized carrier frequencies. One way of obtaining the required frequency control system would be by transmitting a synchronizing frequency of, say, 10,000 or 20,000 cycles on the same wires that are used to carry the program. The synchronization would then fail only in case the program also failed. Tests with broadcast stations in which two stations carrying the same program were supplied from the same frequency source, have been conducted in England and Germany, apparently with considerable promise of usefulness.

The form of common frequency broadcasting that appears most

promising is a system in which the stations transmitting the same program are subdivided into two or three groups. Each group of stations would operate on a common frequency, but a different frequency would be used for each group. When a number of stations broadcast a common program on synchronized carrier waves, listeners who are so located as to be approximately equidistant from the two nearest stations will experience distorted reception and fading. The distortion is due to interference between the two stations with resulting reinforcement of some audio-frequency pitches and the elimination of others, while the fading is caused by changing phase relations between the two received carriers. The approximate locations of these areas of unsatisfactory reception is shown by the shaded area in the top diagram of Fig. 1, in which the dense shading represents the poorest reception.

A second group of stations located in the same general area as the first group, and broadcasting the same program as the first group, but using a new common frequency, would give areas of poor reception as indicated in the middle diagram of Fig. 1. Any listener in the area would then have the choice of receiving the common program from either the first or second group of stations, and would experience satisfactory reception from one or the other of the two groups except when located in the criss-cross shaded areas of the lower diagram of Fig. 1. By superimposing a suitable third group of stations operating on still another common frequency on this diagram, these remaining areas might be largely wiped out, thus insuring that every listener could receive the program from at least one set of stations.

With an arrangement of this type it would be technically possible to broadcast a program from 100 high-powered stations, using only three channels, and to reach substantially all of the receiving sets in the United States. The three channels employed should be adjacent, such as 1000, 1010, and 1020 kc in order that the listener in adjusting his receiver would unconsciously tune to the position of clearest reception without fully realizing the exact situation.

With an interlocking group system of the type described, the present broadcast band would accommodate over thirty nation-wide chains, which, if composed of 100 stations each, would permit simultaneous broadcasting by more than 3000 "super-power" stations. These stations would be necessarily confined to chain programs at night, but in daylight hours could operate singly in the majority of cases. It is questionable as to whether the public would be able to support such a tremendous amount of broadcasting, and the ultimate problem of the future may be not how to restrict the number of stations but rather how to obtain a sufficient number to fill up the places available. The lack

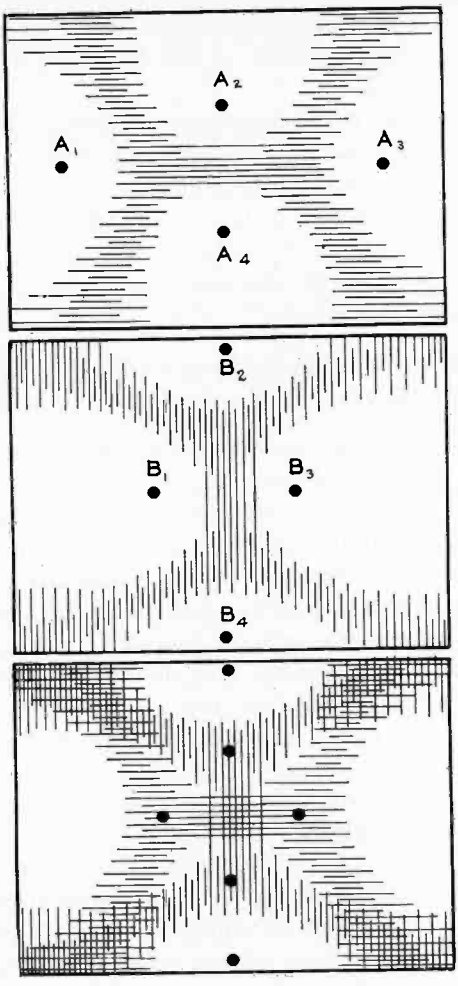

Fig. 1—The shaded areas on the top diagram show the regions of poor reception when stations A_1, A_2, A_3, and A_4 broadcast the same program on a synchronized carrier frequency. The shaded areas in the middle diagram show the regions of poor reception when stations B_1, B_2, B_3, and B_4 broadcast a common program on a synchronized carrier frequency. The lower diagram represents the first two superimposed, and shows the character of reception when both A and B groups of stations transmit the same program, but with each group operating on a different synchronized carrier frequency. The regions of double criss-cross shading indicate the only locations where a listener could not receive the program from either one or the other group of stations, and it is apparent that these remaining areas of poor reception could be eliminated by superimposing a third group of suitably situated stations having a third synchronized carrier frequency.

of suitable stations in certain localities, for example, and the inadequacy of receiver selectivity to insure complete freedom from interference would act as limitations on the working out of such an ideal system.

A constructive plan would be either to reduce gradually the number of channels which a given chain program may occupy, or to assign each chain a frequency band 30 kc wide, and give it adequate time, say two years, to undertake to work out the technical details. After the system is in operation, every chain could be allowed to add new stations in areas not otherwise covered, inasmuch as all members of the chain could be within the 30-kc band.

Technical Problems Involved in Effective Utilization of Short Waves for Telegraph Transmission

Successful operation of channels as narrow as 25 to 200 cycles requires that the transmitted frequency be maintained within 5 to 10 cycles of the assigned value. With short-wave transmission on frequencies in the range from 10,000 to 30,000 kc this corresponds to a stabilization of the absolute frequency to better than one part in a million over indefinitely great time intervals and under commercial conditions. It may be difficult to attain such precision by the use of piezo-electric crystal oscillators, in view of the fact that under the most favorable conditions such oscillators cannot now be counted on to maintain a constant frequency to closer than 3 parts in 100,000 under commercial conditions, and it is not certain that any of the present laboratory standards are able to maintain their absolute frequency to better than 1 part in 100,000 over long periods of time.[9]

A complete realization of the possibilities of short-wave telegraph communication would undoubtedly require the establishment of a frequency synchronizing system in which a master frequency would be radiated from some convenient central location and used to control the frequency of all transmitting stations. Heterodyning frequencies for use at receiving stations could also be derived from the master frequency. The following arrangement would probably handle the situation as far as North America is concerned: a suitably located station would broadcast a master frequency of 15 kc, and a number of frequencies derived from 15 kc, such as 30 kc, and a series of high frequencies such as 3000, 6000, 9000 and 15,000 kc modulated at 15 kc or some sub-harmonic of this master frequency. In addition to the master frequency station there would be perhaps a half-dozen additional sta-

[9] J. H. Dellinger, "The status of frequency standardization," Proc. I.R.E., 16, 579; May, 1928.

tions that would reradiate the master 15-kc signal. These stations could obtain their frequency control either from the 30-kc signal sent out by the central station, or from any of the short-wave signals. Although there would be locations where interference between the several 15-kc carriers might make the reception of this master frequency unsatisfactory, all points in the country would presumably be able to receive either the master frequency or one of the derived frequencies. The development of an international frequency stabilizing system along this line might follow.

Practically any desired frequency could be obtained from the standard frequency by using the principles of frequency addition, frequency subtraction, harmonic and subharmonic generation, combined with the use of an accurately controlled local audio frequency to give intermediate points. Receiving troubles in such a frequency control system caused by atmospherics or "static" could be reduced by making the master frequency receivers extremely selective, and might be practically eliminated by using the master frequency energy to control the frequency but not the amplitude of the local transmitter.

It would of course require large expenditures of money to establish and maintain an adequate frequency control system of the character suggested. If the necessary traffic were at hand, the economic value of the additional transmitting channels thus created would, however, pay the price many times over.

There are many technical expedients now available which can be used to increase greatly the number of telegraph channels possible in a limited frequency band without waiting for such a national synchronizing system. These expedients are all designed to stabilize relative frequencies and can be applied where a number of transmitters can be grouped at one point.

One method of packing a number of radiotelegraph transmitters into a limited frequency band is to use multiple modulation of the same carrier wave. Thus a 200-kw carrier wave could be modulated simultaneously by d-c telegraph, by 200-cycle telegraph, by 400-cycle telegraph, and so on, giving 40 telegraph channels each with 5 kw of carrier wave and with each allowed a 100-cycle signalling side band. The entire forty transmissions would occupy a band of frequencies only 16,000 cycles wide, and would have a possible traffic capacity of about 16,000 words per minute. A number of other schemes of this type are also available, but need not be described here.

It is to be expected that the immediate development in short-wave telegraphy will be toward higher speeds of transmission, and a subdivision of the present channels as better methods of frequency stabiliza-

tion are devised. Ultimately, however, it is probable that these two expedients will not be able to provide all the facilities required, and other more efficient means of utilizing the frequency spectrum will be required.

One way to handle this situation would be to assign not channels, but frequency bands. Thus, instead of allotting 40 scattered channels to a given organization, it could instead be assigned say eight bands, each having the width of five individual channels. The holder of the bands should then be expected to meet the needs of a developing service, so far as possible, by more effectively utilizing the frequencies within the bands previously assigned to him. As five present channels in the neighborhood of 10,000 kc represent a band 100,000 cycles wide, and capable, in the ideal case, of transmitting about 400,000 words per min. using single side-band transmission and the best of modern commercial printing telegraph equipment, it is apparent that such a band allows for a tremendous potential expansion beyond present requirements.

The technical problems involved in the reception of short-wave telegraph signals, when each channel is only 25 to 200 cycles in width, are numerous, but much can be done toward their solution by the proper application of known principles. Thus the selectivity necessary to separate any single channel or group of channels from unwanted transmissions can be obtained by double, triple, or even quadruple detection receivers of the superheterodyne type, such as used on the transatlantic telephone circuit. The limitation here is the constancy of the heterodyning frequencies, but this can be made at least as great as the stability of the transmitted frequencies, which is sufficient. In the case of multiple modulation transmission as described above, an allowance of a few thousand cycles of unused frequencies on each side of the 16,000-cycle band of frequencies would make it possible to separate this band from other communications by a relatively simple double detection (superheterodyne) type of receiver. The separation of the 40 separate signals within the band would call for the use of a highly developed wave-filter system. The elimination of cross modulation between the various signals would require the use of a strictly linear detector. This discussion, while not a complete analysis of the reception problem, indicates that no insurmountable difficulties are present in the receiving apparatus. The costs, however, may be such as to postpone the practical development of such systems until such time as may be warranted by the greater economic demands for circuits.

Conclusion

In the examination that has been made of the possibilities of radio

communication in the transmission of intelligence, several things stand out. Among these are:

First, the fact that the average short-wave channel of widths now assigned can theoretically be made to carry hundreds of high-speed telegraph transmissions instead of one.

Secondly, by the continued development of broadcast chains, and by taking advantage of the possibilities of common frequency broadcasting through use of an "interlocking group" system, the number of stations that can simultaneously operate in the present broadcast band can be increased many fold.

Thirdly, these possibilities in radiotelegraph and broadcast transmission can be realized at least in part with technical means now available.

Fourthly, the Federal Radio Commission might go far toward stimulating the development of common frequency broadcasting by announcing that at the end of an adequate preparatory period the same program will not be allowed on more than three channels, and by assigning a 30-kc band to each extensive chain system.

Fifthly, great encouragement might be given to the more effective use of radiotelegraph channels by assigning bands of frequencies instead of individual channels, and encouraging the development of methods by which each band may be used by an increasing number of transmitters.

Sixthly, television can be expected to play only a small part in radio, and apparently has its future in wire transmission.

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A THERMIONIC VOLTMETER METHOD FOR THE HARMONIC ANALYSIS OF ELECTRICAL WAVES*

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Summary—*A thermionic voltmeter method for the harmonic analysis of complex electrical waves is given. The sensitivity and accuracy of the method are tested by measuring wave forms of known harmonic content. Accuracy greater than 1 per cent (referred to the harmonic) for a harmonic of 10 per cent of the fundamental, and greater than 3 per cent accuracy for a 1 per cent harmonic may be obtained. Examples with oscillograms of various applications of the method are given. Sources of error and limits of sensitivity are discussed.*

Introduction

A KNOWLEDGE of the harmonic content of complex electrical current and voltage waves is useful in many phases of alternating-current practice. A need has been felt for a simple and accurate method of obtaining the amplitude of the harmonic components[1] at commercial and audible frequencies. Many of the excellent methods that have been devised for special purposes[2] are more involved than the type of work here described warrants. It is with these considerations in mind that the present method was developed.

Method

A complex wave form ϵ (to be analyzed for harmonics) is impressed upon the input circuit of a thermionic voltmeter; in series with the above source is a local oscillator capable of being tuned to the frequency of the harmonics of the wave form ϵ. As the frequency of the local oscillator is adjusted approximately to the frequency of the harmonic to be measured, the indicating needle of the anode milliammeter will oscillate slowly in response to the heterodyne difference frequency; the *frequency* of this slow oscillation is the difference between the frequency of the local oscillation and that of the harmonic, and when this difference is made sufficiently small by tuning, one may read the *amplitude*

* Dewey decimal classification: R261.

[1] Measurement of the relative phase positions of the harmonic components is for many purposes unnecessary.

[2] See for example: *Proc. Phys. Soc.*, 40, 228; June, 1925.
R. L. Wegel and C. R. Moore, *Bell Sys. Tech. Jour.*, p. 299, 1924.
A. G. Landeen, *Bell Sys. Tech. Jour.*, p. 231, 1927.
C. R. Moore and A. S. Curtis, *Bell Sys. Tech. Jour.*, p. 217, 1927.

directly in milliamperes. From the amplitude of this heterodyne beat and the amplitude of the local oscillation (as read by the voltmeter when $\epsilon = 0$) one may calculate the amplitude of the harmonic from

$$H = K\frac{I_b}{L}$$

where H is the amplitude of the harmonic, I_b the current amplitude of the beat note in the anode milliammeter A, L the amplitude of the local oscillation, and K a constant to be determined.

The calculation of the constant will first be made for a simplified case, and the results of the analogous procedure for the more general case will be given. The simplified result is, however, a practical one, and it will be shown that the factors introduced by the more exact treatment are below the sensitivity of the experimental method.

The anode current of a three-element vacuum tube is a function of the voltage e_g applied to the grid and the voltage e_p of the anode, other parameters being constant. We have

$$i_a = f(e_g, e_p).$$

For the special case of no external impedance in the anode circuit we may obtain the convenient power series expansion

$$i = a_1 e + a_2 e^2 + a_3 e^3 + \cdots \tag{1}$$

where i is now only the variable component of the anode current and e is the total variable voltage applied to the grid. For the present purpose we shall confine the grid-input voltage to such limits that the static characteristic is essentially quadratic. This necessary condition involves no inconvenience, since with amplifier tubes now available large quadratic limits may be easily obtained.[3] With this stipulation, $a_3 = a_4 = a_5 = 0$. The input voltage is made up of the complex wave ϵ and the local oscillation ϵ_0. We have

$$i = a_1 e + a_2 e^2 = a_1\epsilon + a_1\epsilon_0 + a_2\epsilon^2 + a_2\epsilon_0{}^2 + 2a_2\epsilon\epsilon_0 \tag{2}$$

where

$$\epsilon_0 = E_0 \cos \phi_0$$

and

$$\epsilon = E_1 \cos \phi_1 + E_2 \cos \phi_2 + \cdots \tag{3}$$

$$(\phi_2 = 2\ \phi_1 \text{ etc.}).$$

It is here assumed that the local oscillator wave form is sinusoidal and that the harmonic components of the complex wave are of like phase at the time zero. Substituting (3) in (2) one obtains

[3] Jansky and Feldman, *Jour. A.I.E.E.*, p. 126, February, 1928.

$$\begin{aligned} i = {} & a_1E_0 \cos \phi_0 + a_1E_1 \cos \phi_1 + a_1E_2 \cos \phi_2 + \cdots \\ & + a_2{E_0}^2 \cos^2 \phi_0 + a_2{E_1}^2 \cos^2 \phi_1 + a_2{E_2}^2 \cos^2 \phi_2 + \cdots \\ & + 2a_2E_0E_1 \cos \phi_0 \cos \phi_1 + 2a_2E_0E_2 \cos \phi_0 \cos \phi_2 + \cdots \\ & + 2a_2E_1E_2 \cos \phi_1 \cos \phi_2 + 2a_2E_1E_3 \cos \phi_1 \cos \phi_3 + \cdots \\ & \cdots + \cdots + \cdots + \cdots \end{aligned} \tag{4}$$

Or, grouping terms

$$\begin{aligned} i = {} & a_1 \sum_0^n E_n \cos \phi_n + a_2 \sum_0^n {E_n}^2 \cos^2 \phi_n \\ & + 2a_2 \sum_1^n E_0E_n \cos \phi_0 \cos \phi_n \\ & + a_2 \sum_1^n \sum_1^m E_nE_m \cos \phi_n \cos \phi_m . \\ & \qquad (n \neq m) \end{aligned} \tag{5}$$

By simple trigonometric changes we may write (5) in the form

$$\begin{aligned} i = {} & a_1 \sum_0^n E_n \cos \phi_n + \frac{a_2}{2} \sum_0^n {E_n}^2 + \frac{a_2}{2} \sum_0^n {E_n}^2 \cos 2\phi_n \\ & + a_2 \sum_1^n E_0E_n \cos (\phi_0 + \phi_n) + a_2 \sum_1^n E_0E_n \cos (\phi_0 - \phi_n) \\ & + a_2 \sum_1^n \sum_1^m E_nE_m \cos (\phi_n + \phi_m) + a_2 \sum_1^n \sum_1^m E_nE_m \cos (\phi_n - \phi_m) \\ & \qquad (n \neq m) \qquad\qquad\qquad (n \neq m) \end{aligned} \tag{6}$$

where the squared terms have been resolved into zero-frequency and double-frequency components, and the product terms have been written in terms of the sum and difference frequencies.

We shall define δi as that portion of the plate current i which is readable by a d-c meter. The quantity δi will contain all steady components of i as well as those variable terms of frequency below the period of the indicator in the plate-current meter. We have therefore

$$\delta i = \frac{a_2}{2} \sum_0^n {E_n}^2 + a_2 \sum_1^n E_0E_n \cos (\phi_0 - \phi_n) \tag{7}$$

where only one member of the difference frequency is present at one time. It is to be noted that the summation (last member of the right-hand side of equation (7)) contains all the possible difference frequencies that might be obtained under the assumptions involved, but

that for any given adjustment of the local oscillator to approximately the frequency of a harmonic only one of these differences may be made small at one time. Let us apply this result to a simple case. Let the complex wave form ϵ be composed of the two components ϵ_1 and ϵ_3.

$$\epsilon = \epsilon_1 + \epsilon_3 = E_1 \cos 100t + E_3 \cos 300t \tag{8}$$

The presence of a third harmonic may be ascertained and the amplitude obtained by tuning the local oscillator to near the frequency of the third harmonic for purposes of obtaining a small difference. Specifically, suppose

$$\epsilon_0 = E_0 \cos 299t \tag{9}$$

we may substitute in (7) to obtain

$$\delta i = \frac{a_2}{2}E_0^2 + \frac{a_2}{2}E_1^2 + \frac{a_2}{2}E_3^2 + a_2 E_0 E_3 \cos 1t. \tag{10}$$

The local oscillator thus tuned to near the frequency of the third harmonic in the unknown wave form produces the heterodyne beat of frequency $1/2\pi$ and current amplitude $a_2E_0E_3$. The indicating needle of the anode milliammeter swings through $I_b = 2a_2E_0E_3$ amperes since the cosine term takes positive and negative values. We may then determine E_3 the amplitude of the third harmonic from

$$E_3 = \frac{I_b}{2a_2E_0} \tag{11}$$

where I_b is read directly, E_0 is determined by placing $\epsilon = 0$, since the instrument is calibrated as a voltmeter. The coefficient a_2 is determined graphically or more simply from the voltmeter calibration. When used as a voltmeter operating over the quadratic portion of the static characteristic the calibration is given by

$$\Delta i = \frac{a_2}{2}E^2_{\text{peak}} = a_2 E^2_{\text{r.m.s.}} \tag{12}$$

The coefficient a_2 is constant in the limits noted and is obtainable at once from the r.m.s. calibration.

If alternating voltages are in r.m.s. values, (11) becomes

$$E_{3_{\text{r.m.s.}}} = \frac{I_b(\text{D.C.})}{4a_2E_{0_{\text{r.m.s.}}}}. \tag{13}$$

The constant K noted in the first paragraph is therefore $1/4a_2$.

If one assumes general wave forms for both the unknown wave form and the local oscillator, that is

$$\epsilon = E_1 \cos(\phi_1 + \psi_1) + E_2 \cos(\phi_2 + \psi_2) + \cdots$$
$$\epsilon_0 = V_1 \cos(v_1 + k_1) + V_2 \cos(v_2 + k_2) + \cdots \tag{14}$$

the expression for δi takes the following form:

$$\delta i = \frac{a_2}{2} \sum_1^n E_n^2 + \frac{a_2}{2} \sum_1^n V_n^2 + a_2 \sum_1^n \sum_1^m E_n V_m \cos (\phi_n - v_m + \psi_n - k_m). \tag{15}$$

The expression (15) indicates the possibility of obtaining beat notes between higher harmonics of the local oscillator and the unknown wave form. However, the frequency of the harmonic beats of this type is different from that given by (7), and moreover with reasonable assumptions as to the wave form of the local oscillator one may easily calculate for any given case that these spurious beat notes are of insufficient amplitude to appear within the limit of sensitivity of the anode milliam-

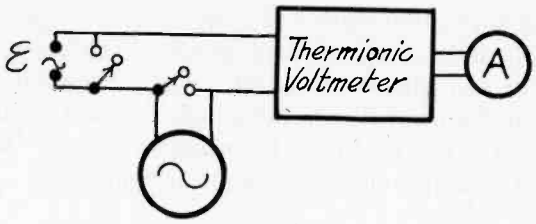

Fig. 1

meter. In the work that has been done by the author with this method heterodyne beats between higher harmonics have not been noted; if present, they should appear superimposed on the fundamental beat expected from (7). From this and other considerations noted later it is concluded that the requirements imposed on the wave form of the local oscillator are easily satisfied experimentally.

It should be particularly noted that a quadratic static characteristic is both necessary and sufficient for harmonic analysis purposes; a quadratic calibration curve follows of a necessity, but is not sufficient, since a_3 or higher odd coefficients may be present. When operation is confined to the quadratic limits of the static characteristic, wave form error is absent.

The sensitivity of the method follows as a result of the heterodyne amplification that is obtained. The amplitude of the beat note is proportional to the product of the contributing amplitudes, and the only deterrents to making this as large as desired are the quadratic limits, or the zero-frequency component which eventually forces the beat note off the anode milliammeter scale. The latter may of course be balanced out.

Experimental Section

In Fig. 2 the square root of the plate current $\sqrt{I_p}$ is plotted for different values of grid voltage, the data being obtained from the static characteristic of an R. C. A. UX-171 amplifier tube. The static characteristic is quadratic in grid voltage and plate current between $-E_g=4$ volts and $-E_g=20$ volts within the limits of accuracy of this method. No difficulty is experienced in obtaining a quadratic portion of 16 volts[4]; a 5-volt portion or possibly less could be used for the purpose. If we chose $E_g=-13.5$ volts and $I_p=5$ ma as the operating point, it is clear that a single sinusoidal component of peak value less than 8 volts,

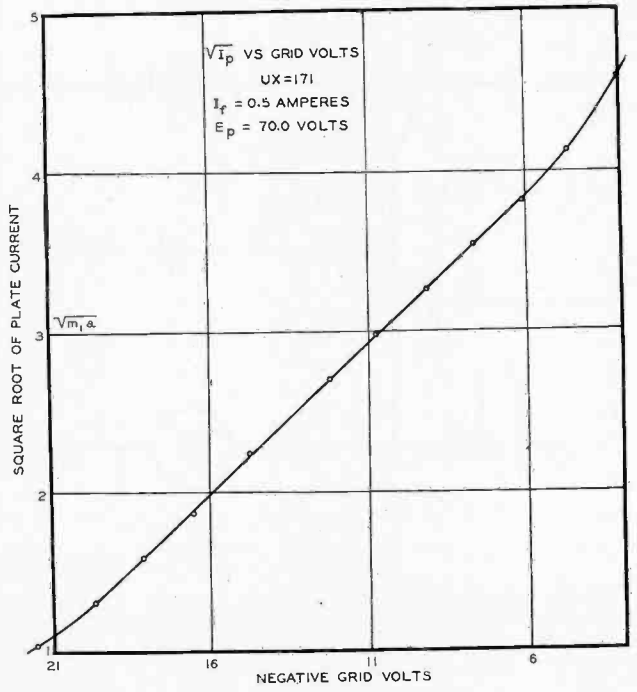

Fig. 2

or in general a sum of components of total peak value less than 8 volts may be applied to the grid without exceeding the quadratic limits. The change in anode current for maximum applied alternating voltage will be of the order 1 ma and it will evidently be necessary to balance out the steady component of 5 ma. A convenient circuit is given in Fig. 3.

[4] Tubes of the 171 type, such as R.C.A. UX-171, Cunningham Cx-371 or CeCo J-71 etc., all with the 0.5-ampere filament, have been found very suitable. Of these tubes that have been tested the extent of the quadratic portion of the characteristic has invariably been found to be greater than 7 volts and often as large as 25 grid volts (as determined graphically).

The coefficient a_2 as determined from Fig. 2 is 0.0322 ma/volts^2 which agrees within the limit of error with a_2 determined from the voltmeter calibration. The r.m.s. amplitudes of the harmonic components are then calculated from

$$H = \frac{I_b}{0.129L}. \tag{16}$$

In the following pages the results of a number of analyses of current and voltage wave forms are given. The first group purports to establish the practical sensitivity and accuracy of the method, while the second is illustrative of convenient applications.

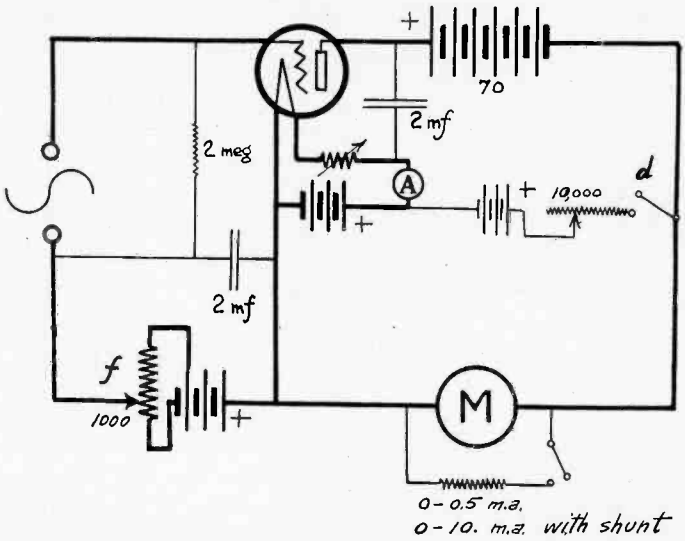

Fig. 3—Filament current is adjusted by ammeter A. An adjustment of M (shunted, d open) to 5 *ma* by grid potentiometer compensates to a high degree of approximation for changes in voltage of the grid and plate batteries. The resistance across the input protects the microammeter in case of open input circuit.

For the purpose of arriving at an estimate of the accuracy and practical sensitivity, known wave forms have been measured. For example, a fourth harmonic (supplied locally) may be added to 60-cycle lighting current which normally has no fourth harmonic. The supplied harmonic is measured as a fundamental at its source, and its subsequent measurement as a harmonic component furnishes a test of the accuracy of the method. Table I contains three groups of measurements of harmonics of respectively 10 per cent, 5 per cent, and 1 per cent of the fundamental.

TABLE I

$$H=\frac{I_b}{0.124\,L}$$

10 per cent harmonic						
I_b (μa)	86	85	85	93	90	77
L (r.m.s.)	3.59	3.46	3.48	3.36	3.47	3.184
H (at source)	0.189	0.20	0.20	0.219	0.208	0.193
H (as harmonic)	0.193	0.198	0.198	0.223	0.209	0.195
Per cent agreement	+3.2	−1.0	−1.0	+1.8	+0.48	+1.0
Per cent agreement, six measurements +0.75						
5 per cent harmonic						
I_b (μa)	36	40	40	41	40	40
L (r.m.s.)	3.31	3.30	3.29	3.44	3.47	3.53
H (at Source)	0.0965	0.0964	0.0975	0.0910	0.0911	0.0911
H (as harmonic)	0.0877	0.0978	0.0981	0.0961	0.0929	0.0914
Per cent agreement	−1.2	+1.5	+063	+5.5	+1.9	+0.55
Per cent agreement, six measurements +1.5 per cent						
1 per cent harmonic						
I_b (μa)	7.5	7.0	8.5	9.0	7.5	8.5	9.5	9.5
L (r.m.s.)	2.73	2.73	2.42	2.38	3.03	3.04	2.5	2.49
H (at source)	0.0228	0.0228	0.0305	0.0306	0.0224	0.0225	0.0303	0.0303
H (as harmonic)	0.0222	0.0207	0.0283	0.0305	0.0200	0.0225	0.0307	0.0307
Per cent agreement	−0.9	−9.2	−7.2	−0.33	−10.7	0.0	+1.3	+1.3
Per cent agreement, six measurements −3.2 per cent								

The data in Table I was obtained under favorable experimental conditions, i.e., constant frequency and voltage of the measured source.

The next example of interest is the peaked wave form shown in the oscillogram[5] of Fig. 4. This voltage wave form was produced by charging a condenser in series with a high resistance by means of a square wave form from a commutator. The measurements of the harmonics may of course be verified, on the presumption that the wave form is perfect, since the Fourier expansion is familiar, being given by

$$E=\frac{1}{I^2}\sin\phi+\frac{1}{3^2}\sin 3\phi+\frac{1}{5^2}\sin 5\phi+\cdots.$$

The series of measurements is given in Table II. Since considerable difficulty was experienced with changing frequency, and voltage fluc-

[5] The wave form as shown is badly distorted because of amplification and the small time constant of the condenser-resistance combination which was necessary to secure sufficient amplitude for oscillographing. When measurements were taken, however, the time constant $=RC$ was $4.7\times10^{4}\times10^{-6}=0.047$ sec., while the fundamental frequency of the squared wave was 60 p. p. s.; it is, therefore, safe to assume that deviations from an accurate peaked wave were not large.

tuations, this analysis is to be considered as an example of results obtainable under unfavorable experimental conditions.

It is upon the groups of examples just given that estimates of the accuracy and sensitivity of the method are based. It may be therefore concluded that a harmonic of amplitude 10 per cent of the fundamental may be measured to 1 per cent accuracy; similarly a harmonic of amplitude 1 per cent of the fundamental may be measured with at least 3 per cent accuracy under favorable conditions. A harmonic as small as 0.1 per cent of the fundamental may be detected but not measured within the sensitivity of the arrangement described.[6]

The method of testing the accuracy is not entirely satisfactory,

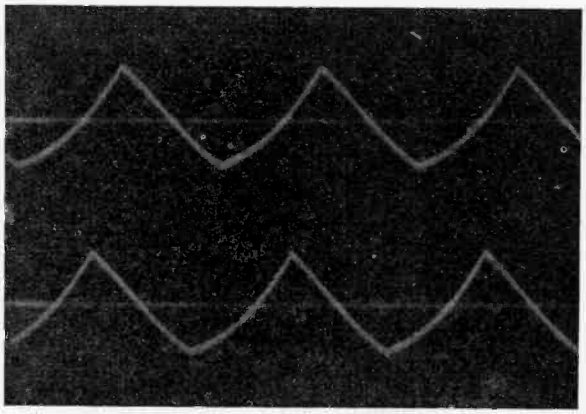

Fig. 4

TABLE II

$$H = \frac{I_b}{0.129\,L}$$

Peaked wave form, r.m.s. input 1.11 volts

First Harmonic

I_b (μa)	385	181	235	200	80
L (r.m.s. volts)	2.81	1.36	1.82	1.60	0.68
H (r.m.s. volts)	1.06	1.03	1.00	0.97	0.91

H_1 average five determinations $=0.994$

Third Harmonic

I_b (μa)	38	50	50	43
L (r.m.s. volts)	2.70	3.46	3.46	2.97
H (r.m.s. volts)	0.109	0.112	0.112	0.112

H_3 average four determinations $=0.111$

[6] For many purposes the percentage accuracy referred to the fundamental is the significant figure. The accuracy expressed in this notation is numerically much greater.

Fifth Harmonic

I_b (μa)	23	18	20	13
L (r.m.s. volts)	3.64	3.91	3.16	3.35
H (r.m.s. volts)	0.049	0.0357	0.049	0.030

H_5 average four determinations $=0.0408$

Seventh Harmonic

I_b (μa)	10	9	9	11	10
L (r.m.s. volts)	3.48	3.66	3.53	3.53	3.54
H (r.m.s. volts)	0.0223	0.0191	0.0198	0.024	0.0219

H_7 average five determinations $=0.0216$

Summary of Results: Relative Amplitudes Compared to Fourier Coefficients

Harmonic	1	2	3	4	5	6	7	8
Four. coeff. peaked wave.	1.00	0	0.1111	0	0.0400	0	0.0204	0
As measured	1.00	0	0.1116	0	0.0410	0	0.0217	0

since the percentage agreement between calculated and measured values also involves the errors in the measurement of the harmonic at the source (in the case of the first example), or unknown imperfections in the measured wave form (in the second example); these errors are probably small.

When relative amplitudes of the harmonic components are the consideration, and this is very often the case, it is not necessary to know the coefficient a_2 since it enters as a factor into all the harmonic amplitude measurements.

Several interesting examples will now be given which illustrate applications of the method. The oscillogram (Fig. 5) is a portion of the voltage across a resistance shunting a variable frequency generator. The harmonics as measured are[7] (each amplitude is the average of three determinations):

Variable Frequency Generator, at 60 p.p.s.

Harmonic	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Per cent total r.m.s.		0	2.3	0	2.6	0	1.8	0	0	0	8.25	0	4.6	0

From inspection of the oscillogram the presence of the thirteenth harmonic might not be inferred; but one may measure the amplitudes with calipers with sufficient accuracy to indicate proper magnitudes for an eleventh and thirteenth harmonic in additive phase in the middle of the half cycle and subtractive phase at the zero line.

[7] Harmonic amplitudes of less that 0.1 per cent of the fundamental will be considered zero for lack of better information.

Harmonic production in ferromagnetic inductances is well-known and has been extensively studied. In Fig. 6 are oscillograms of the current wave in an iron-core inductance for successively increasing magnetization current (the knee of the magnetization curve occurs at approximately 1 ampere). Data obtained from the analysis is given in Fig. 8; for different values of the magnetization current are plotted the produced harmonics expressed in percentages of the total r.m.s. current. The 1000-cycle time wave shown in Fig. 6 is furnished by a General Radio fork maintained buzzer. Its analysis gives the following harmonic content expressed in percentages of the amplitude of the total r.m.s. value:

G. R. 1000-cycle Fork Buzzer

Harmonic	1	2	3	4	5	6	7	8	9	10
Per cent total r.m.s.	96.7	9.40	5.76	2.31	1.09	1.37	0.78	0.69	0.57	0

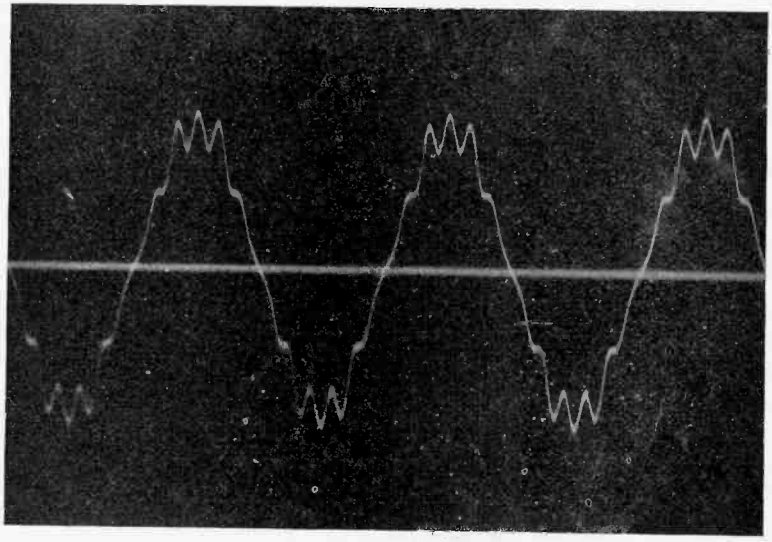

Fig. 5

An analysis of the city lighting current is of interest. The voltage measured was obtained from a 1000-ohm resistance shunted across the line. The harmonics present in this source depend to a large extent upon the particular type of load on the line; the determination here given represents characteristic values for this particular source. An exceptionally pure wave form may be noted.

60-cycle Lighting Current

Harmonic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Per cent total r.m.s.		0	.21	0	1.31	0	.08	0	*	0	0	0	0	0	0	0	*	0	*	0

* Detected but not measured

Discussions of Sources of Error

The possible sources of error inherent in the method arise from two causes: (a) poor wave form in the local oscillator, and (b) non-quadratic curvature of the static characteristic. It is easily shown that these factors may be eliminated as difficulties of any consequence.

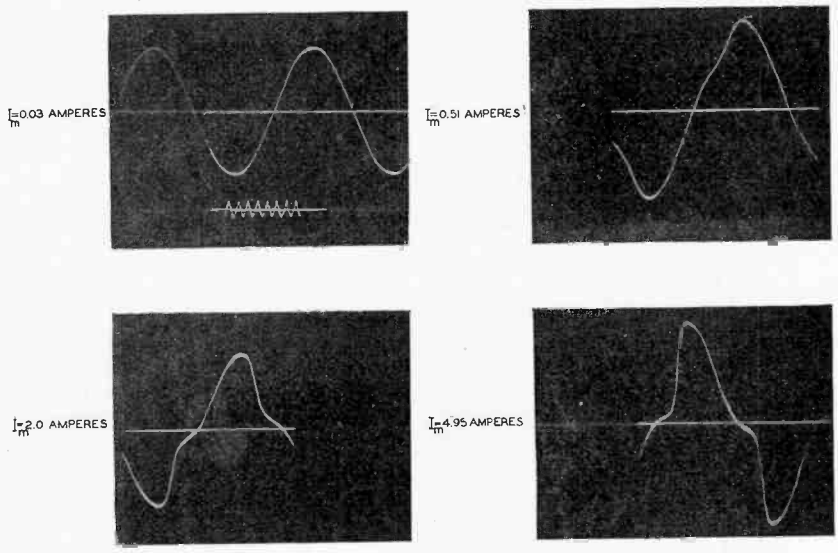

Fig. 6

(a) *Oscillator Wave Form.* Poor oscillator wave form may introduce an error in two ways. The harmonics of the oscillator may produce a heterodyne beat with harmonics in the unknown wave form. The frequency of these beats, is, however, different from that produced by the fundamental, and moreover, with reasonable assumptions as to the wave form of the local oscillator (largest harmonic component 2 per cent—5 per cent of the fundamental), one may easily calculate that such beats have insufficient amplitude to appear in the indicating (0-500 μa) microammeter. The choice of sensitivity of the anode milliammeter is thus of considerable importance. For example, in the present case a full scale deflection of 500 μa is small enough to preclude the possibility of exceeding the quadratic limits of the characteristic with any practical

input voltage, while complications of the type above noted do not produce a readable deflection.

The wave form of the oscillator also enters into the determination of the local oscillator voltage L, equation (16) above, but since r.m.s. values are measured by the voltmeter, a 10 per cent harmonic would be required to produce 1 per cent error; hence with like assumptions as to the purity of wave form easily obtainable in a practical oscillator this source of error becomes insignificant.

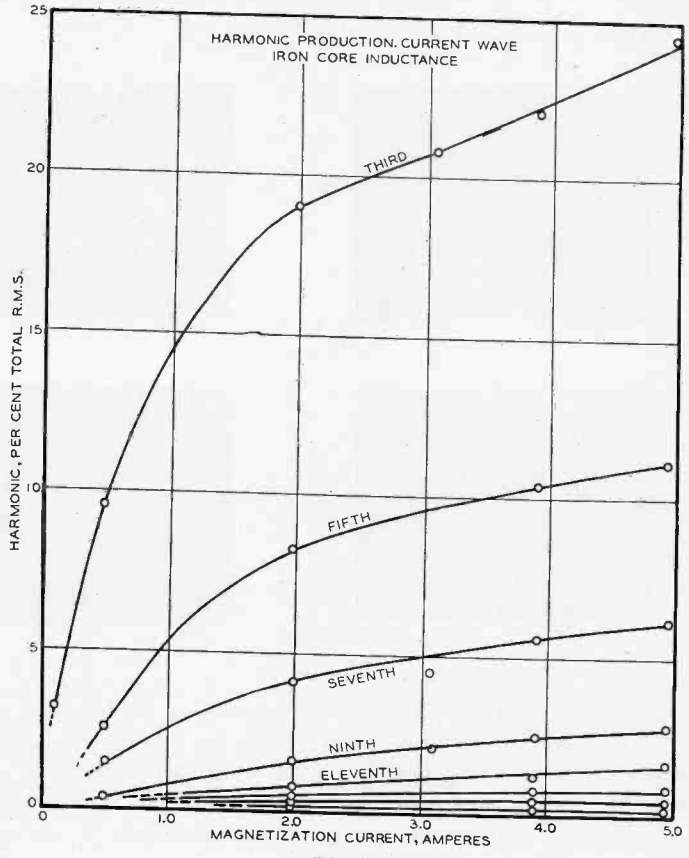

Fig. 7

(b) *Non-quadratic Curvature.* Curvature other than quadratic may produce an error in the determination of the second harmonic, since if the coefficient a_3 of the series expansion for the characteristic is not zero, the apparent second harmonic of the same beat frequency has the amplitude

$$\frac{I_b}{2} = a_2 E_0 E_2 + \frac{3}{4} E_0 E_1^2$$

where E_0 is the amplitude of the local oscillation, E_2 the second harmonic, which may be zero, and E_1 is the fundamental in the unknown source. Even though E_2 is zero the portion $3/4\ a_3 E_1^2 E_0$ of the same beat frequency produces an apparent second harmonic. For any general case a correction may be applied by the relation just given, since the coefficient a_3 is easily determined (0.00036 ma/V^3 for the tube here used). However, the correction may be easily avoided by the simple precaution of keeping the input voltage of the unknown wave form small, of the order 0.5 volt. This is only necessary when measuring the second harmonic.

Similarly the presence of the coefficient a_4 might be suspected; this was tested by measuring 60-cycle lighting current from which the normal third harmonic has been filtered. No apparent third harmonic could be detected. The leading term in the expression for the apparent third harmonic is

$$\frac{a_4}{2} E_1^3 E_0$$

from which it is concluded that the coefficient a_4 is zero or smaller than 0.000004 ma/V^4. Higher coefficients may be tested in a similar manner; such tests have yielded negative results.

Sensitivity Limits

The sensitivity limits with a (0-500) microammeter in the plate circuit have been indicated above. Maximum sensitivity to small harmonics is had when the r.m.s. voltage furnished by the measured source and the r.m.s. voltage of the oscillator are equal. A considerable gain in sensitivity (of order five times) may be obtained under good experimental conditions by balancing out the zero-frequency components in the microammeter deflection, and increasing the current sensitivity of this instrument. This has been done with some success. Any increase in sensitivity in this direction requires constant voltage characteristics in the measured source and a proportionate improvement in the wave form of the local oscillator. The harmonics 6, 7, 8, and 9 in the analysis of the wave form of the G. R. 1000-cycle fork vibrator given above were determined by the double balance method here described.

Discussion and Conclusion

The method of harmonic analysis here given is thought to be capable of wide application; the simplicity of the experimental procedure

suggests its ready use in many laboratory problems such as the measurement of amplifier distortion, oscillator wave form, and the like. The high impedance characteristics of the voltmeter input circuit insures practically zero power drain from the measured voltage. The wave form requirements on the auxiliary oscillator are easily met, and the calibration need not be accurately known. The principal limitation imposed on the method, inherent sensitivity limits excepted, is that the voltage and frequency of the source shall be constant enough to allow tuning to slow beat frequency. The relative phase positions of the harmonic components is not determined, but for many purposes this is unnecessary. It is interesting to note that the calculation here given does not apply uniquely to the vacuum tube, but to any circuit element of quadratic characteristics and frequency independence.

The versatility and usefulness of the type of thermionic voltmeter described (plate-current rectifier operating on quadratic characteristic) is such as to make it almost indispensable for many types of laboratory work. In addition to harmonic analysis as described, the instrument is useful as a high-impedance voltmeter (range 0.4—4.0 volts r.m.s.) for measurement of current, voltage, inductance, capacitance, power factor, amplification factor, resonance in coupled circuits, signal strength, and the like. The frequency independence to 3×10^6 p.p.s. is assured, and wave-form error is entirely absent. In conjunction with a local oscillator and without further calibration, one may measure very small alternating voltages (range 10—2000 mv r.m.s. by beat notes, similar to the method described by Aiken.[8] The amplitude of the fundamental of the measured voltage is given by

$$E_{\text{r.m.s.}} = \frac{I_b}{4a_2 E_{0\ \text{r.m.s.}}}.$$

In conclusion, I wish to express my sincere indebtedness to the late Professor E. M. Terry, and to Professor Leo. J. Peters for valued suggestions.

[8] C. B. Aiken, *Jour. Opt. Soc. Amer. and Rev. Scien. Instr.*, p. 440, December, 1928.

Proceedings of the Institute of Radio Engineers
Volume 18, Number 1 *January, 1930*

BOOK REVIEWS

The ABC of Television or Seeing by Radio, by Raymond Francis Yates. Norman W. Henley Publishing Co., 205 pages, 78 line drawings, and 12 full-page halftone illustrations.

"The ABC of Television," by Raymond Francis Yates, former editor of *Popular Radio*, is a convenient collection of information regarding the general theory of television and still picture transmission and reception, and of practical details for the guidance of amateur experimenters and constructors. The volume is addressed particularly to the latter group rather than to the scientist or laboratory technician.

Among the systems described in detail are the television device demonstrated by the Bell Telephone Laboratories, due to Herbert E. Ives; the Ranger system of still picture transmission; the television principles demonstrated by E. F. W. Alexanderson at Schenectady; the drum scanner and the prismatic disk of Jenkins; and the corona system of still picture reproduction invented by Austin G. Cooley. Constructional details of the latter and of the conventional manually synchronized spiral scanning disk type of television reproducer, including all the necessary associated equipment such as high-frequency receiver, amplifiers and speed control equipment, are described in the usual manner of publications appealing to the amateur experimenter. Much relevant information regarding sources of supply for photo-electric cells, characteristics of neon lamps and selenium cells, and synchronizing systems are included in this comprehensive volume.

As a whole, the manual is interestingly written and reflects the author's long experience in writing for the home experimenter. The volume is a clear and comprehensive starting point for the beginner in television.

EDGAR H. FELIX[1]

[1] Radio Consultant, National Electrical Manufacturers' Association, New York City.

The Physical Principles of Wireless, by J. A. Ratcliffe. Published by E. P. Dutton and Co., 104 pages. Price, $1.15.

Contents: Oscillatory circuits; valves; wireless transmitters; reception of wireless signals; wireless telephony; amplifiers; miscellaneous.

This book gives a concise and fairly elementary treatment of the fundamentals of radio. The fresh and illuminating explanations make it an excellent book from which to get clearly and quickly the most important scientific principles of radio with the minimum of details. As suggested by the title, it is a treatment of physical principles and should not be confused with the more common elementary radio manuals containing extensive detailed descriptions of apparatus and circuits.

S. S. KIRBY*

* Assistant Physicist, Bureau of Standards, Washington, D. C.

BOOKS RECEIVED

The Radio Manual, by GEORGE E. STERLING, edited by Robert S. Kruse. Published by D. Van Nostrand Company, Inc., 1929, revised. 798 pages, 5×8 inches, illustrated. Price, $6.00. Contents: preface to second edition; introduction; elementary electricity and magnetism; motor generators; storage batteries and charging circuits; theory and application of the vacuum tube; fundamental circuits employed in vacuum-tube transmitters; modulation systems and associated apparatus; wavementers, piezo-electric oscillators, wavetraps and field-strength measuring apparatus; marine vacuum-tube transmitters; radio broadcasting equipment; the arc radio transmitter; spark transmitters; commercial radio receivers and associated apparatus; the auto-alarm; radio direction finders; aircraft radio equipment; amateur short-wave apparatus; practical television and radio movies; radio interference; radio laws of the U. S. and international telegraphic conference; handling and abstracting traffic; four appendices.

Radio Traffic Manual and Operating Regulations, by RUDOLPH L. DUNCAN and CHARLES E. DREW. Published by John Wiley and Sons, Inc., 1929. 188 pages, illustrated, 6½×9½ inches, paper cover. Price, $2.00. Contents: foreword; acquiring the code—use of *Q* signals; operating rules and regulations of the Radiomarine Corporation of America; International Radiotelegraph Convention; U. S. radio act of 1927; ship act of July 23, 1912; regulations governing the issuance of radio operators' licenses; index.

Electricity—What It Is and How it Acts, by ANDREW W. KRAMER. Published by Technical Publishing Company, Chicago, 1929. 274 pages, illustrated, 5×7½ inches, cloth binding. Price, $3.00. Contents: preface; introduction, fundamental conceptions; arrangement of electrons in atoms; structure of atoms of various elements; matter in the aggregate; electric conduction through gases; conduction in liquids; electric conduction in solids; relation of atomic structure to conduction; difference between insulators and conductors; theory of the condenser; production of the magnetic field; theory of the solenoid; reaction between current carrying conductors; determination of the mass of the electron; determining the charge of the electron; the Millikan oil drop experiment; the numerical value of the electronic charge; principles of thermionic emission; the two-electrode vacuum tube; further considerations regarding the two-electrode vacuum tube; the three-electrode vacuum tube; the disruptive discharge; theories of the electric arc; concluding considerations of the electric arc.

BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

Booklets describing the characteristics of the following transmitting and receiving tubes may be obtained without charge from the Radiotron Division, Radio-Victor Corporation of America, 233 Broadway, New York City, N.Y.

UV-203A Triode. Oscillator and R-F Power Amplifier. Output—75 watts.
UV-206 Triode. Oscillator and R-F Power Amplifier. Output—1,000 watts.
UV-207 Triode. (Water Cooled) Oscillator and R-F Power Amplifier. Output—20,000 watts.
UV-211 Triode. Oscillator, Power Amplifier, and Modulator. Maximum Undistorted A-F Output—10 watts.
UV-214 Diode. (Water Cooled) Maximum Peak Inverse Voltage—50,000 volts. Maximum Peak Plate Current—7.5 amperes.
UV-217A Diode. Maximum A-C Supply Voltage (R.M.S.)—1,500 volts. Maximum D-C Load Current—200 milliamperes.

UV-217C Diode. Maximum A-C Supply Voltage (R.M.S.)—3,000 volts. Maximum D-C Load Current—150 milliamperes.
UV-218 Diode. Maximum Peak Inverse Voltage—50,000 volts. Maximum Peak Plate Current—0.75 amperes.
UY-224 Tetrode. R-F Amplifier for A-C Operation in Receivers.
UY-227 Triode. Detector and Amplifier for A-C Operation.
UX-245 triode. Power Amplifier for A-C Operation in Receivers. Maximum Undistorted A-F Output—1.6 watts.
UX-841 Triode. Voltage Amplifier. Maximum Peak A-F Voltage Output— 250 volts.
UX-842 Triode. A-F Power Amplifier and Modulator. Maximum Undistorted A-F Output—3 watts.
UV-845 Triode. Modulator and A-F Power Amplifier. Maximum Undistorted A-F Output—20 watts.
UX-852 Triode. Oscillator and R-F Power Amplifier for High-Frequency Transmission. Power Output—75 watts.
UX-860 Tetrode. R-F Power Amplifier for High-Frequency Transmission. Power Output—75 watts.
UX-864 Triode. Non-Microphonic Amplifier or Detector.
UX-865 Tetrode. R-F Power Amplifier and Oscillator. Power Output—7.5 watts.
UX-866 Diode. (Mercury Vapor) Maximum Peak Inverse Voltage—5,000 volts. Maximum Peak Plate Current—0.6 amperes.
UV-872 Diode. (Mercury Vapor) Maximum Peak Inverse Voltage—5,000 volts. Maximum Peak Plate Current—2.5 amperes.
UV-1651 Diode. Maximum A-C Supply Voltage (R.M.S.)—4,000 volts, Maximum D-C Load Current— 250 milliamperes.

The "Disturbo-Ducon" is a filter for power-line disturbances and is described in a new leaflet issued by the Dubilier Condenser Corporation, 342 Madison Avenue, New York City.

A new bulletin of the Amrad Corp., of Medford Hillside, Mass., describes the mershon condenser and some of its uses.

The Yaxley Manufacturing Co. announces a new booklet describing radio convenience outlets for use in hotels, residences, hospitals, schools, and apartments.

A "Condenser and Resistor Manual" is available without cost to all who request it. Address the Aerovox Wireless Corp., 70 Washington Street, Brooklyn, N. Y.

The condenser transmitter of Jenkins and Adair is described in their bulletin No. 6 which is available upon request.

A pamphlet entitled "Polymet Radio Essentials" covers the condensers and resistors manufactured by the Polymet Mfg. Corp., 829 East 134th Street, New York City.

A new radio catalog has recently been published by the Jefferson Electric Co., who will be glad to mail you a copy upon request. Their address is 1500 South Laflin Street, Chicago, Ill.

The Lynch Mfg. Co., formerly Arthur H. Lynch, Inc., 1775 Broadway, New York City, offers a folder describing its complete line of resistors.

A leaflet describing multiple variable condensers and other products of the DeJur-Amsco Corp. may be had by addressing that organization at 418 Broome Street, New York City.

The Colin B. Kennedy Corp., of South Bend, Ind., will supply copies of its service manual to all interested.

Proceedings of the Institute of Radio Engineers
Volume 18, Number 1 *January, 1930*

MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The periodicals can be secured from their publishers and can be consulted at large public libraries.

R000. Radio Communication

R005 Weinberger, J. The National Broadcasting Company, a technical organization for broadcasting. Proc.I. R. E., 17, pp. 1969–85; November, 1929.

(The origin and the present organization of the National Broadcasting Co. are reviewed. A description is given of its studio facilities and apparatus and of its arrangements for program distribution. Certain of its program achievements are recorded.)

R007 Dellinger, J. H. Radio broadcasting regulation and legislation. Proc. I. R. E., 17, pp. 2006–2010; November, 1929.

(The principles that radio waves potentially interfere with one another and that their transmission is characterized by extreme vagaries are basically involved in radio regulation. On these principles frequency, power, and time assignments to broadcasting stations are made with a view to the greatest public satisfaction.)

R100. Radio Principles

R113 Hahnemann, W. Die Bedeutung der ultrakurzen Wellen für die elektrische Nachrichtentechnik, insbesondere die der Wellenlängen von 1-m abwärts. (The importance of ultra short waves for electric communication technique, especially those of about 1-m wavelength.) *Elektrische-Nachrichten Technik*, 6, pp. 365–374; September, 1929.

(A general discussion of the properties of short waves from 100 to 1 meters (300 to 30,000 kc) and description of experiments carried out with 50-cm waves employing parabolic reflectors made up of sheet copper.)

R113 Fassbender, H. Versuche mit ultrakurzen Wellen im Flugzeugverkehr. (Experiments with ultra short waves in aircraft work.) *Elektrische-Nachrichten Technik*, 6, pp. 358–65; September, 1929.

(Description of communication tests from ground to plane and from plane to ground on 3.7 meters up to distances of 137 km. A short treatise is given on the possible application of ultra short waves to aircraft communication channels and beacons.)

R113.4 Ponte, M. and Rocard, Y. Sur la couche ionisee de la haute atmosphere. (On the ionized layer of the upper atmosphere.) L'Onde Electrique, 8, pp. 306–14; July, 1929.

(Transmission experiments have shown that below 5000 kc the zone of silence does not appear. This value is used as the critical value above which there is "dielectric reflection" and below which there is "metallic reflection". It is related to the frequency of collision of electrons in the upper atmosphere. Using this theory and the formulas of the physics of the atmosphere the height of the Kennelly-Heaviside layer is calculated.)

R113.4 Kenrick, G. W. and Jen, C. K. Further observations of radio transmission and the heights of the Kennelly-Heaviside layer. PROC. I. R. E., 17, pp. 2034–2052; November, 1929.

(Further observations on radio transmission phenomena associated with reflections of radio pulse and spark signals are described with a theoretical discussion of the form of the variation of index of refraction which seems best adapted to explain the observed phenomena. Results of long-wave field-strength observations are also presented.)

R113.5 Eve, A. S., Keys, D. A., Lee, F. W. The penetration of rock by electromagnetic waves and audio frequencies. PROC. I. R. E., 17, pp. 2072–74; November, 1929.

(Experiments performed at Mammoth Cave, Kentucky are described. Radio signals from distant stations as well as signals of radio and audio frequencies transmitted from directly above were received at various depths in the cave at points remote from the entrance. Since no conductors led from the cave it was concluded that the waves were passing through the solid rock.)

R113.5 Sreenivasan, K. On the relation between long-wave reception and certain terrestrial and solar phenomena. PROC. I. R. E., 17, pp. 1793–1814; October, 1929.

(Signal intensity measurements of Madras (Fort) Radio working on 75 kc made at the Radio Laboratory of the Indian Institute of Science, Bangalore, between March, 1926, and August, 1927, are reported. Certain correlations are found between the reception, temperature, atmospheric ozone, sunspots, and terrestrial magnetism.)

R113.6 Breit, G. The significance of observations of the phase of radio echoes. PROC. I. R. E., 17, pp. 1815–21; October, 1929.

(An interferometer method of observing the phase of radio echoes has been developed by Tuve and Hafstad. It is shown that by measurement on reflections with low retardation the ratio between the changes in the equivalent height found through the interferometer method and in the effective height found by measurement of the echo retardation is a measure of how much of the change is due to the layer moving as a whole and how much is due to a redistribution of electron densities through the layer.)

R113.6 Hafstad, L. R. and Tuve, M. A. An echo interference method for the study of radio wave paths. PROC. I. R. E., 17, pp. 1786–92; October, 1929.

(The rate of change of the radio-frequency phase of separate downcoming echoes has been experimentally determined by an interferometer method. Oscillograms show the echoes to alternately add to and subtract from a constant pickup in the radio receiver from the crystal-controlled oscillator of the nearby pulse transmitter. Changes are regular but the time of a 360-deg. phase change on 4435 kc varies from 1 to 60 sec. and at times changes between these limits in as short time as 15 min.)

R113.6 Pederson, P. O. Wireless echoes of long delay. PROC. I. R. E., 17, pp. 1750–85; October, 1929.

(Shows mathematically that radio echoes occurring after 10 sec. cannot be due to propagation of waves within the earth's atmosphere, that echoes occurring after intervals up to 30 sec. are due to propagation along or reflection from Strömer bands as explained in *Nature* (122, p. 681; 1928); that echoes after several minutes must be from outside the space in which the earth's magnetic field exerts appreciable effect. Transmissions at various wavelengths are also treated.)

R114 Joscheck, R. Registrierung von atmosphärischen Störungen. (Recording of atmospheric disturbances.) *Elektrische-Nachrichten Technik*, 6, pp. 341–349; September, 1929.

(Observations made at the University of Halle include the form, duration, intensity and audible impression of such disturbances as well as the relation between these characteristics.)

R130.4 Kusunose, Y. Calculation of characteristics and the design of triodes. PROC. I. R. E., **17**, pp. 1706–1749; October, 1929.

(The calculation of the characteristics and constants of a triode from its electrode structure is illustrated and the derivation of various working conditions from its static characteristics is explained. A dynamic characteristic diagram is presented applicable to any type of triode in evaluating the working voltages, currents, and power whether the tube be used as amplifier, oscillator or modulator. The designing procedure is outlined for a typical case in which the use of the triode is indicated and its power output is given.)

R131 Sowerby, A. L. M. The pentode as an anode rectifier. *Wireless Wld. and Radio Rev.*, **25**, pp. 391–94; October 2, 1929.

(The results of an experimental investigation show that the pentode forms a satisfactory resistance-coupled rectifier for small, moderately high-frequency voltages. It is in general twice as sensitive as a triode and introduces about the same amount of damping into the grid circuit. (Concluded from p. 286, September 18, 1929 *Wireless Wld. and Radio Review.*)

R131 Rocard, M. Y. Les propriétés d'écran des grilles les lampes ecran. (The shielding properties of the grids in the shield-grid tubes.) *L'Onde Electrique*, **8**, pp. 347–52; August, 1929.

(On classical electrostatic theory the effect of the capacity between two electrodes in a vacuum tube of the insertion of a third electrode between them is deduced. This is done for the triode and for the shield-grid tube. The close relation of the shielding property of the electrode to the amplification factor of the tube is shown.)

R132 Harris, S. The grid suppressor circuit. *Radio Engineering*, pp. 43–45; October, 1929.

(Discussion of regenerative amplifier from view-point of transmission and oscillation characteristic.)

R133 Smith-Rose, R. L. Transmitting on ultra short waves. *Wireless Wld. and Radio Rev.*, **25**, pp. 398–402; October 9, 1929.

(A popular article abstracted from paper in *Experimental Wireless and W. Engr.*, for October, 1929.)

R133 Smith-Rose, R. L. and McPetrie, J. S. Experimental transmitting and receiving apparatus for ultra short waves (to be concluded). *Experimental Wireless and Wireless Engr.*, **6**, pp. 532–542; October, 1929.

(Early work on the production and application of short electromagnetic waves, damped and undamped is reviewed, and circuits suitable for short-wave generators are analyzed. These circuits are of the single and double tube type.)

R133 Smith-Rose, R. L. and McPetrie, J. S. Experimental transmitting and receiving apparatus for ultra short waves (conclusion). *Experimental Wireless and Wireless Engr.*, **6**, pp. 605–619; November, 1929.

(The discussion of apparatus for the production and reception of short electromagnetic waves—including generators, receiving sets, antennas, frequency meters, and direction finders.)

R133 Podliasky, I. Sur l'appareillage permettant l'etude du spectre musical. (Concerning apparatus for the study of the audible frequencies). *L'Onde Electrique*, **8**, pp. 297–305; July, 1929.

(The principles underlying two types of audible frequency generators are explained. These types are the beat-frequency tube generator and the motor-driven alternator. Use of the latter in obtaining response curves of radio circuits is illustrated.)

R134 Harris, S. Notes on the detection of large signals. PROC. I. R. E., **17**, 1834–39; October, 1929.

(The effect of large signals applied to the grid of a detector is discussed. It is shown that signals even as small as 50 mv appreciably affect the tube parameters and influence the

frequency distortion. The nature of detector overloading is discussed and overload curves of the plate rectifier are presented.)

R134.4 Fromy, E. Les effets secondaires de la reaction. (Secondary effects in regeneration.) *L'Onde Electrique*, **8**, pp. 281–296; July, 1929.

(Experimental anamolies in the functioning of a regenerative stage cannot be explained by the simple theory. A theoretic study of the secondary effects of regeneration is presented, and the qualitative conclusions drawn are shown to be in accord with actual experience.)

R141.1 Pack, S. W. C. The frequency departure of thermionic oscillators from the "LC" value. *Experimental Wireless and Wireless Engr.*, **6**, pp. 554–64; October, 1929.

(The results of an investigation of the departure of the frequency of a tube a-c generator from the "LC" value under varying conditions of grid coupling, grid bias, filament current, plate voltage, and added resistance in the oscillatory circuit are given. These are presented as curves. The practical results are discussed briefly from the theoretical point of view.)

R144 Griffiths, W. H. F. Conductors compared. *Wireless Wld. and Radio Rev.*, **25**, pp. 515–18; November 6, 1929.

(How electroplating affects high-frequency resistance.)

R149 Barclay, W. A. The numerical estimation of grid rectification for small signal amplitudes. *Experimental Wireless and Wireless Engr.*, **6**, pp. 596–601; November, 1929.

(Two charts for finding rapidly the numerical value of the grid rectification of a tube for small signal amplitudes are explained. Their use is illustrated.)

R149 Butterworth, S. Note on the apparent demodulation of a weak station by a stronger one. *Experimental Wireless and Wireless Engr.*, **6**, pp. 619–21; November, 1929.

(The demodulating effect of a strong carrier wave on a weak carrier wave when the two are of slightly differing frequencies and are being simultaneously received is analyzed for the case of a perfect rectifier.)

R200. Radio Measurements and Standardization

R210 Lange, E. H. and Myers, J. A. Static and motional impedance of a magnetostriction resonator. Proc. I. R. E., **17**, pp. 1687–1705; October, 1929.

(The equivalent series inductance and resistance of a long solenoid with nickel-steel bar is investigated in relation to the excitation frequency for frequencies up to 14000 cycles per second. The results are discussed in relation to the theory of flux distribution in the bar. The effect of motion of the bar under the action of magnetostriction is measured in terms of the motional impedance and the circle diagram is obtained. The theory of total impedance, static and motional, is given and the nature of the angular displacement of the resonant circle is indicated.)

R210 Jimbo, S. Measurement of frequency. Proc. I. R. E., **17**, pp. 2011–2033; November, 1929.

(A stroboscopic method of absolute measurement of frequency is described. The performance of various kinds of tuning fork generators is discussed mathematically. A new type with a magnetic device of such a nature as to make the effect on the frequency of the electromagnetic controlling force extremely small is described. Factors affecting the frequency of quartz radio-frequency generators are outlined. Several types of electrical and mechanical resonators are compared with regard to their usefulness as frequency standards.)

R210 Decaux, B. La mesure absolue des frequences radio-electriques. (The absolute measurement of radio frequencies.) *L'Onde Electrique*, **8**, pp. 325–46; August, 1929.

(The ordinary installation for the absolute measurement of frequencies includes a standard of time, a standard low-frequency generator, a standard high-frequency generator and a set of multiple and sub-multiple generators. The principles of these elements of the apparatus and precautions to be taken in using them are outlined. Installations used in important laboratories in the United States and in Europe are briefly described.)

R210 Salinger, H. Zur Theorie der Frequenzanalyse mittels Suchtons. (Theory of frequency analysis by means of a search frequency.) *Elektrische-Nachrichten Technik*, **6**, pp. 293–302; August, 1929.

(Mathematical theory and description of methods used for such tests are given. Limits of application of the methods are discussed.)

R230 Turner, H. M. Inductance as affected by the initial magnetic state air gap and superposed currents. PROC. I. R. E., **17**, pp. 1822–33; October, 1929.

(Families of curves are presented to show the variation of the inductance of a coil with change in the air gap of the core and in the superposed currents, alternating and direct. The effect of the initial magnetic state of the core is also shown. The curves experimentally obtained are discussed.)

R230 Grover, F. W. The calculation of the inductance of single-layer coils and spirals wound with wire of large cross section. PROC. I. R. E., **17**, pp. 2053–63; November, 1929.

(Formulas obtained by an extension of the Rosa method are given for the calculation of the inductance of single-layer coils and spirals wound with wire of large cross section. Tables are included from which the geometric mean distances of rectangles which enter into the formulas may be readily obtained.)

R230 Leithäuser, G. Ueber Hochohmwiderstände und ein neues Verfahren zu ihrer Prüfung. (High ohmic resistances and a new departure in their testing.) *Elektrische-Nachrichten Technik*, **6**, pp. 335–338; August, 1929.

(New industrial methods for testing resistance values of 0.01 to 10 megohms).

R244 Owen, G. E. Dielectric losses at high frequencies. *Physical Review*, **34**, pp. 1035–39; October, 1929.

(The power loss in pieces of dielectrics in high-frequency alternating fields is measured by a calorimetric method in which the heat produced in the dielectric is compared with that produced in a resistor carrying a measured direct current. For vulcanized fibre, celluloid, rubberdam and glass the loss is found to be proportional to the frequency and to the square of the applied voltage.)

R270 Kiebitz, F. Die Wellenausbreitung des Deutschlandsenders. (Wave propagation of German transmitters.) *Elektrische-Nachrichten Technik*, **6**, pp. 303–306; August, 1929.

(Field intensity measurements, made in the fall of 1928 at about 100 places at distances of 50-100 km around the "Deutschland" radio transmitter at Zeesen, indicate greater absorption at close range than at greater distances. A map is given illustrating the effect, and two possible explanations are suggested.)

R270 Kaufmann, W. Registrierungen der Feldstarke von Rundfunkwellen in Königsberg i. Pr. (The recording of field strength of broadcast waves in Konigsberg in East Prussia.) *Elektrische-Nachrichten Technik*, **6**, pp. 349–54; September, 1929.

(Field-intensity measurements made at Königsberg on two transmitters; one at Oslo 800 km distant, the other at Landenberg 1100 km distant. Field-intensity graphs are presented showing short and long period variations which differ for the two transmitting stations.)

R300. Radio Apparatus and Equipment

R320 Everett, W. L., and Byrne, J. F. Single wire transmission lines for short-wave antennas. Proc. I. R. E., **17**, pp. 1840–67; October, 1929.

(The phenomena of high-frequency transmission lines are discussed. It is shown that the single wire transmission line is an effective method of feeding a Hertz antenna. The frequency which makes the antenna a pure resistance termination is first determined and then the proper point of connection between the line and the antenna is found to make the terminating resistance equal to the characteristic impedance of the line. With such a termination, experiment and theory show that radiation from the line is small and that it will act efficiently.)

R330 Rocard, M. Y. Sur le calcul theorique des lampes a plusieurs electrodes. (Concerning the theoretic calculation of multi-electrode tubes.) *L'Onde Electrique*, **8**, pp. 353–61; August, 1929.

(The formula for the fictitious voltage to be used in Langmuir's formula for the total emission current from the filament of a multi-electrode tube is derived for the single-grid, two-grid and three-grid tube. A new formula, giving a better approximation than the old, is offered for the calculation of the amplification factor of a triode.)

R330 Cocking, W. T. An English output tube, the pentode. *Radio Broadcast*, **15**, pp. 360–62; October, 1929.

(General information on this tube. A study of performance and possibilities.)

R330 Lamb, J. J. The UV-845—A low impedance linear power amplifier and modulator tube of the 50-watt type. *QST*, **13**, pp. 24–26; November, 1929.

(Characteristics of UV-845.)

R330.4 Engle, E. W. Tantalum, tungsten and molybdenum in vacuum tubes. *Radio Engineering*, **9**, pp. 51–53; October, 1929.

(The characteristics and applications of these rare metals in vacuum-tube design.)

R342.5 D'Arcy, E. W. Public address and centralized radio systems. *Radio Engineering*, pp. 62–63; October, 1929.

(Power amplifier and power supply units discussed.)

R343 Smith-Rose, R. L., and McPetrie, J. S. Below 10 meters. *Wireless Wld. and Radio Rev.*, **25**, pp. 470–73; October 23, 1929.

(Some experimental receiving apparatus for ultra-short waves.)

R344.3 Blair, W. R. and Cohen, L. Wave resonance tuning and application to radio transmission. Proc. I. R. E., **17**, pp. 1893–96; October, 1929.

(Methods embodying the principle of wave resonance tuning for eliminating the harmonics of a transmitter and for attaining multiplex transmission on a single antenna are described.)

R344.3 Nelson, E. L. Radio broadcasting transmitters and related transmission phenomena. Proc. I. R. E., **17**, pp. 1949–68; November, 1929.

(Recent developments in American practice concerning radio broadcast transmitters are briefly discussed. The attainment of a high degree of fidelity, the improvement in frequency maintenance through the adoption of piezo-electric frequency control, the tendency to employ higher per cent modulation, and the effort to reduce harmonic radiation are noted. Descriptive material and photographs pertaining to several new commercial transmitting equipments are included. Reference is also made to related transmission problems.)

R357 Janovsky, W. Frequenzerniedrigung durch Eisenwandler. (Frequency reduction by means of iron-core coils.) *Zeitschrift für Hochfrequenztechnik*, **34**, pp. 81–87; September, 1929.

(By means of coils having saturated iron cores the frequency of a generator was reduced to ⅓ and accompanying phenomena were studied with the Braun tube oscillograph.)

R358 Verman, L. C. and Reich, H. J. A vacuum-tube regulator for large power units. PROC. I. R. E., 17, pp. 2075–81; November, 1929.

(The application of a d-c vacuum-tube amplifier to the control of voltage of a large d-c generator is described. Curves are given showing improvement of regulation obtained with this device over that obtained with the vibrating contact type of regulator.)

R370 Cohen, L. Circuit tuning by wave resonance and applications to radio reception. PROC. I. R. E., 17, pp. 1868–92; October, 1929.

(Theoretical consideration of the wave resonance system of tuning with distributed values of inductance and capacity is given, together with circuit arrangements embodying this method of tuning. It is shown that a high degree of selectivity is obtainable and that it offers an effective method for the elimination of interference. Multiplexing in both transmission and reception of radio signals can be readily realized.)

R376.3 Clarke, H. M. Moving coil loud speakers. *Experimental Wireless and Wireless Engr.*, 6, pp. 602–604; November, 1929.

(Experimental curves show that the electrical input to a moving coil loudspeaker may be made more nearly constant at all frequencies by the use of a compensation winding. This may take the form of copper cylinders in the air gap and extending over the neighboring iron of the magnet. Resonances in the motional impedance are smoothed out by the use of suitable shunting filters.)

R382 Griffiths, W. H. F. Notes on standard inductances for wavemeters and other radio frequency purposes. *Experimental Wireless and Wireless Engr.*, 6, pp. 543–49; October, 1929.

(A method is presented for constructing inductances on forms compensated to give constant inductance under wide temperature variation. In addition to the inconstancy due to age, lack of robustness, and temperature coefficient, that due to changes of self capacity and effective resistance with variation of humidity is considered.)

R400. RADIO COMMUNICATION SYSTEMS

R450 Clark, A. B. Wire line systems for national broadcasting. PROC. I. R. E., 17, pp. 1998–2005; November, 1929.

(The wire networks provided in the United States by the Bell Telephone system for the national distribution of broadcasts are described.)

R600. RADIO STATIONS: EQUIPMENT, OPERATION AND MANAGEMENT

R610 Little, D. G. Speech input equipment. PROC. I. R. E., 17, pp. 1986–97; November, 1929.

(The apparatus used in converting sound energy into electrical energy of a kind and amount suitable for use in a broadcasting transmitter is briefly described. This includes the microphone, amplifiers, and line equalizers. In addition a description is given of supplementary equipment for monitoring, intercommunicating, and supplying power.)

R800. NON-RADIO SUBJECTS

535.3 Toulon, P. Recentes applications des cellules photo-electriques associees aux amplificateurs. (Recent applications of photo-electric cells associated with amplifiers.) *L'Onde Electrique*, 8, pp. 315–322; July, 1929.

(On account of the weak current furnished by a photo-electric cell enormous amplification must be used in conjunction with it. Suitable amplifying arrangements are discussed and precautions to be taken in the construction of the amplifier are pointed out.)

535.3 Toulon, P. Les applications des cellules photo-electriques. (The applications of photo-electric cells.) *L'Onde Electrique*, 8, pp. 362–372; August, 1929.

(The practical application of the photo-electric cell is illustrated by the description of two pieces of apparatus. The first records automatically the time at which the line is crossed on the race track. The second, called a "Phonoluxmeter," compares with great precision the intensities of sources of light.)

535.3 Metcalf, G. F. Operating characteristics in photoelectric tubes. PROC. I. R. E., **17**, pp. 2064–71; November, 1929.

(The characteristics of photo-electric tubes with regard to their engineering applications are discussed. Definitions of photometric terms are given with a few special terms essential to photo-electric tube work. Characteristic curves are given for typical tubes. An appendix of photometric formulas and conversion factors is provided.)

621.314.3 Osnos, M. Eisenverluste von Frequenz-Transformatoren. (Iron losses in frequency transformers.) *Zeits. für Hochfrequenztechnik*, **34**, pp. 87–89; September, 1929.

(Results of tests made at no load and at full load.)

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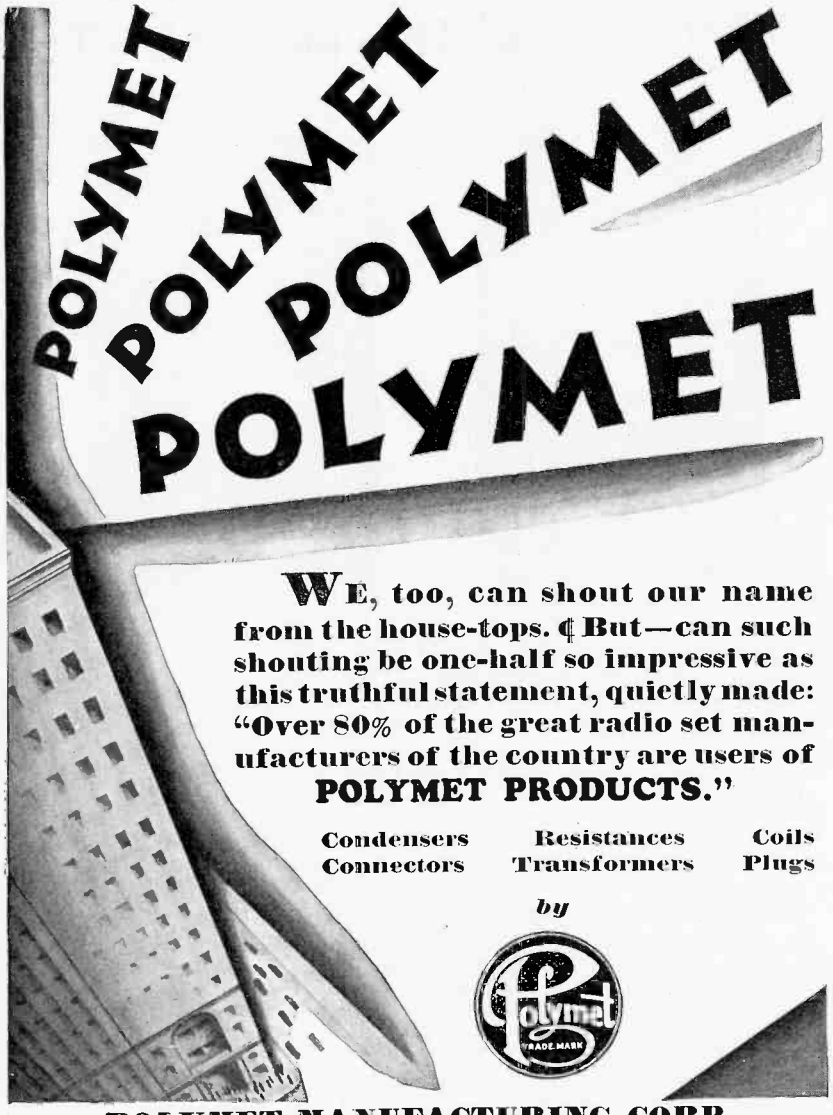

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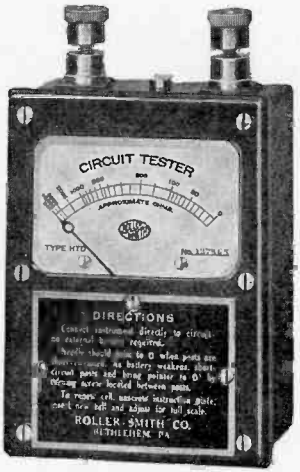

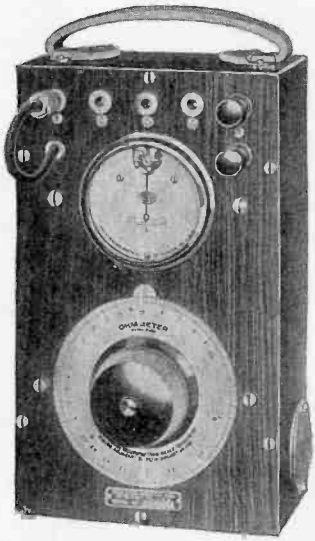

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ROLLER-SMITH COMPANY
Electrical Measuring and Protective Apparatus

Main Office:
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Offices in principal cities in U. S. A. and Canada
Representatives in Australia, Cuba, Japan and Philippine Islands

WITH EVEREADY RAYTHEON 4-PILLAR TUBES, YOU CAN GET THE MOST FROM YOUR PRESENT RADIO RECEIVER

PEOPLE in all parts of the country are telling of the greater power, increased distance, improved tone, and quick action of these remarkable new tubes. The reason is that Eveready Raytheons are built stronger—immune to the bumps and jolts of shipment and handling. They come to you in as perfect condition as when they leave our laboratory test-room.

The Eveready Raytheon *4-Pillar construction* is exclusive and patented. Examine the illustration at the bottom of this page. See how the elements of this tube are anchored at eight points.

This is of particular importance in tubes of the 280 rectifier and 224 screen-grid type which have heavier elements, and in tubes used for push-pull audio amplification, where uniform characteristics are most essential. Eveready Raytheon *4-Pillar* tubes come in all types. At your dealer's. He also has the famous BH tube for "B" units.

NATIONAL CARBON CO., INC.
General Offices:
New York, N. Y.

Branches: Chicago, Kansas City, New York, San Francisco.

EVEREADY RAYTHEON

TRADE MARKS

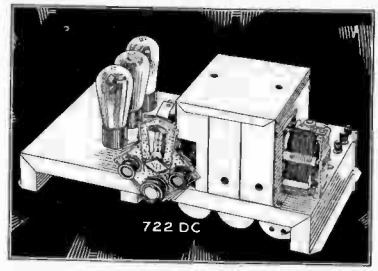
Unit of Union Carbide and Carbon Corporation

Showing the exclusive, patented Eveready Raytheon *4-Pillar* construction. Note the sturdy four-cornered glass stem, the four heavy wire supports, and the bracing by a stiff mica sheet at the top.

EVEREADY RAYTHEON SCREEN-GRID TUBE, ER 224. The weight of the four large elements in this type of tube makes the exclusive Eveready Raytheon *4-Pillar* construction vitally important.

SM --And Now "722" Results for Battery Users!

The S-M laboratories are glad to announce the 722DC—a new high-performance battery-operated receiver which is a fitting companion to the all-electric 722. While it incorporates all the new circuit refinements of the 722 (a.c.), it has been developed to fit the special requirements of the ideal battery receiver.



S-M 722DC

It has four tuned circuits including a "siamese" band-selector circuit used as an antenna coupler. This double tuned circuit is followed by two of the S.M. 123 high-gain interstage tuned transformers used in the 722 (a.c.). The unusually uniform minimum to maximum gain ratio of 1 to 1.5 has been maintained.

S-M 249

The volume is controlled by changing the potential on the screen-grids, which gives a very smooth uniform control from zero to maximum stage. The S-M 270 transformer is used to couple the first audio tube to the two power tubes, which are connected in push pull. The use of resistance coupling in the first stage, together with the low-ratio push-pull transformer and the low-impedance '12A tube in the first stage, gives such a flat frequency characteristic that the quality of the reproduction is virtually limited only by the speaker itself.

Tubes required: 3—'22, 3—'12A. Wired, less tubes, $57.50. Parts total $38.50.

The S-M 722 (a.c.) contains two stages of screen-grid r.f. amplification, a screen-grid power detector, resistance coupled to a '27 first audio stage, and two '45 tubes in push-pull in the power stage. It employs four tuned circuits, two in a band-filter between antenna and first r.f. stage, and two in cascade. It is tuned by an illuminated drum dial controlling a die-cast, "bath-tub" four-gang condenser with individual compensators. All r.f. circuits are individually bypassed; coils are individually shielded, as are r.f. and detector tubes and three sections of the gang-condenser.

The 722 (a.c.) uses 3—'24 tubes, 1—'27, 3—'45 and 1—'80. Wired less tubes, $74.75 net, parts total $52.90.

New Filament Transformer

The S-M 249 Filament Transformer, a companion to the 247, meets exactly the requirements of modern receivers using heater and '45 type tubes. The center-tapped secondary (2.5 volt, 3 amp.) is for use especially with '45 tubes, and another 2.5 volt winding will supply 9 amp. for 5 heater type ('27, '24) tubes. Ratings are conservative: 50 per cent overload permissable for short intervals. Price, $3 net.

Detailed instructions for building the 722DC Band-Selector Six are to be found in DATA SHEET No. 18. If you are not getting DATA SHEETS and RADIOBUILDERS regularly write us.

SILVER-MARSHALL, *Inc.* 6411 WEST 65TH STREET CHICAGO, U. S. A.

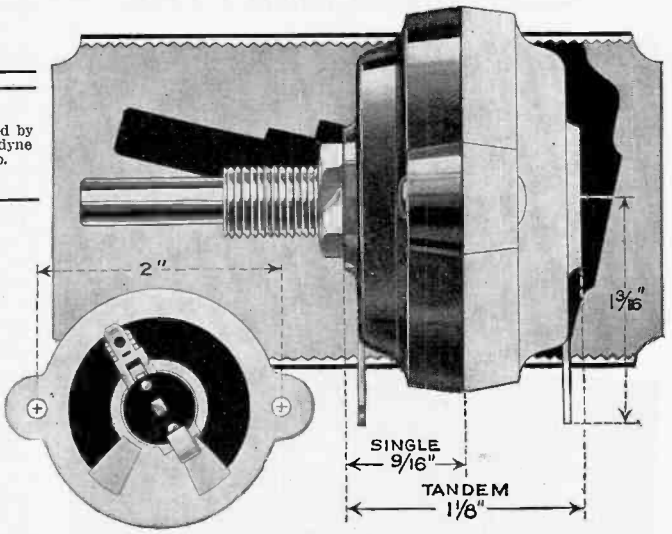
ELECTRAD Model "B" Super-TONATROL

Longer-Lived, Smoother Operating

DUAL-UNIT VOLUME CONTROL

Licensed by Technidyne Corp.

U.S. Patents 1034103—1034104 and Pats. Pend.

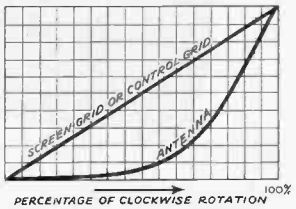


THE New Dual-Unit Model "B" Super-TONATROL effectively combines the advantages of tapered volume control in the antenna circuit and uniform control of screen grid or plate voltage—both on one shaft.

The Model "B" has all the superior operating characteristics of the Model "A" Super-TONATROL plus greater compactness. It has a 3-watt resistance element *permanently* fused to vitreous enameled metal plate and pure silver floating contact with *stepless* variation.

The Dual-Unit models afford complete circuit isolation through a unique method of insulating the rotor shaft. Mechanism enclosed in a handsome Bakelite case, and is practically immune to changes in temperature or humidity. One-hole panel or baseboard mounting.

Can be made with all usual resistance ratings and curves in single as well as tandem units.



The diagram illustrates the typical curves of dual units. A tapered resistance is used in the antenna circuit—a uniform resistance in the grid control circuit. The resistance variation in the antenna circuit is extremely small during the first half of the knob rotation which assures smoother control of powerful signals.

175 Varick St., New York, N.Y.

ELECTRAD INC.

ELECTRAD, INC., Dept. PE1, 175 Varick St., New York.
Please send details and blueprint on the Super-TONATROL Model "B" to

Name.....

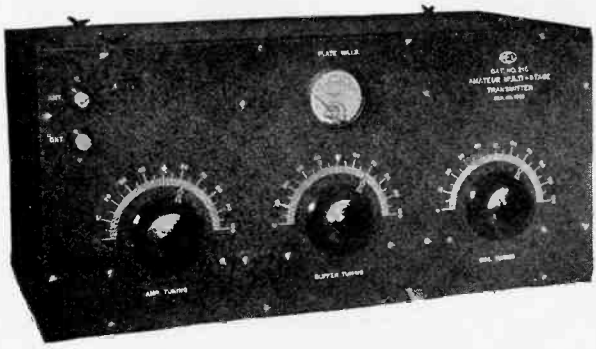
Address.....

For Exclusive Amateur Purposes

REL MULTI-STAGE TRANSMITTER

First time offered at a price within the reach of everyone

No longer need to envy the fellows who operate expensive high power crystal control transmitters . You can secure one of the new REL multi-stage transmitter kits and attain absolute frequency stability plus a pure crystal note for telegraph purposes. If you desire telephony you are offered the most modern 100% system of modulation. Tone, frequency precision, quality and consistency are yours for a very small investment. Install an REL Catalog No. 215 basic unit in your station. Use your present power supply and various other antenna equipment. Modernize your station. Join the ranks of the quality transmitters.



Catalog No. 215 basic CW telegraph unit housed in metal case measuring 9" high x 19" wide x 10" deep. Designed to employ UY-227 master oscillator tube, UY-224 screen grid buffer tube and UX-245 power amplifier tube. Can be used as an independent CW telegraph transmitter capable of supplying 10 to 15 watts to the antenna. May be used for telephone purposes by attaching external REL modulator unit Cat. #225. Will thereby employ 100% system of modulation.

KIT PRICE $56.00

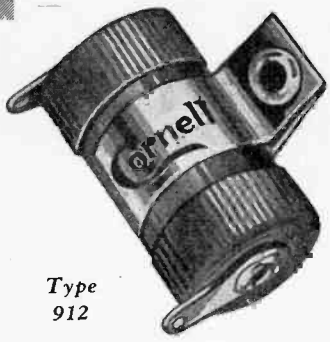
Descriptive Literature Forwarded Upon Request

OUR SHORT WAVE EXPERIMENTAL STATION BROADCASTS EVERY WEDNESDAY AND FRIDAY EVENING BETWEEN 8 AND 10 P.M. E.S.T. ON A FREQUENCY OF 8650 KC.

REL MANUFACTURES A COMPLETE LINE OF APPARATUS FOR SHORT WAVE TRANSMISSION AND RECEPTION

Radio Engineering Laboratories, Inc.

100 Wilbur Ave. Long Island City, N.Y., U.S.A.



Type 912

NEW!

By Pass Condenser

This is a specially designed by-pass condenser made in capacities ranging from .05 to .5. It can be had with insulated mountings or with terminal mountings. The unit is made in a specially treated, rigid, paper case, and is extremely inexpensive, ranging well below the market quotations for condensers of these capacities.

Cornell

FILTER CONDENSERS, BY-PASS CONDENSERS, RADIO INTERFERENCE FILTERS, POWER FACTOR CORRECTION BANKS

In choosing your source of supply for condensers, consider these three requisites—the quality of the product, price, and ability of the manufacturer to give service. For many years Cornell has measured up to these requirements in serving many of radio's largest set manufacturers. We can do the same for you. Let us quote on your requirements or special classifications. Your inquiry will receive immediate quotations and samples will be furnished upon request.

Write for a Sample "Cub" Condenser and Catalog of Complete Line of Cornell Products.

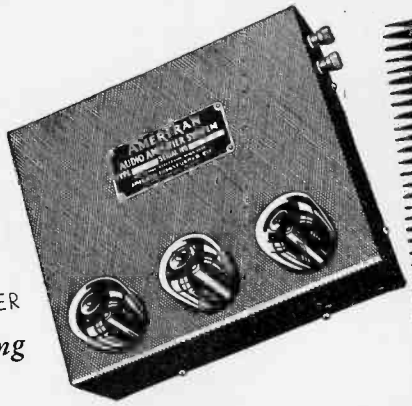
Cornell Electric Mfg. Co., Inc.

LONG ISLAND CITY, NEW YORK

FULL VOLUME

OR THE MEREST WHISPER

With no distortion along the entire range



The AmerTran Push-Pull Amplifier, Type 2-AP*, is designed for radio listeners who truly appreciate fine music and its reproduction exactly as broadcast. With efficient loud speakers it will furnish ample volume for dancing in a large hall and agreeable rendition in a moderate sized auditorium. Or you can tune down a musical program to a faint, melodious background for an evening by the fireside.

There is no distortion at any volume. The shrill, bird-like treble of the flute has the same rich quality as the somber bass of organ or cello.

The Type 2-AP is a high quality two-stage transformer coupled audio amplifier with a push-pull power stage. It is designed for A. C. operation with a--27 A. C. tube in the first stage followed by standard power tubes in the push-pull stage, and is intended to be connected to the detector of any good receiver and operated from an A. C. power supply system, such as the AmerTran Power Box, Type 21-D.

For complete information on the Type 2-AP Amplifier, write for Bulletin 1075-A.

AMERICAN TRANSFORMER COMPANY
172 Emmet Street, Newark, N. J.

AMERTRAN
TRADE MARK REG.U.S.PAT.OFF.

Quality Radio Products

*Licensed under patents of the Radio Corporation of America and associated companies for radio, amateur, experimental and broadcast reception.

AMERICAN TRANSFORMER CO., 172 Emmet St., Newark, N.J. I.R.E.—1-30

Gentlemen:
Please send me Bulletin 1075-A containing complete information on Type 2-AP Amplifier.

Name..... Street.....

Town..... State.....

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New Thinking—New Awakening—New Alertness
New Seizing of Advantages

A Tidal Wave

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These Facts affect you directly or indirectly. You can't escape them. They affect your company; your work; your own interests. You owe it to yourself to get them. And to realize all they mean to you.

We do not care what your position is; or whether you write "officially" for your company, or "personally" for yourself. The Full CONTENTS OUTLINE of these Industrial Fact-Sheets is yours for the asking. (Please state work you do; company; what it makes, or kind of service it deals in). These are Facts that if seized rightly may be of inestimable importance in your own work, advancement and prosperity.

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Here are Facts that connect directly to matters you are earnestly thinking about right now;—operations,—cost-reductions,—safety in competition, — design development, — betterments,—volume,—profits,—prosperity.

There is no question about it. This tidal wave of new thinking has force behind it. It is getting somewhere.

As a business man you want to be on the wave, not under it. We are here offering you some of the FACTS that are causing it.

Send for the OUTLINE OF CONTENTS. Do it today. There is no charge; no obligation.

A Letter or Card. Or Write on Margin:

Fact-Sheets of Industry; L-2
N. V. F. Co., Wilmington, Del.

Please send me OUTLINE OF CONTENTS, without charge or obligation. ...My Name...My Address...Company ...Product or Business...My Position or Kind of Work, or Department.

[Please State whether writing officially for Company, or Personally for self.]

AS a movement in line with national measures for further improvement of business conditions and of the circuit of producing, earning, consuming, equipping, etc.;—and as the initial step in this democratizing of inter-industry knowledge (which, under present conditions, is more needed by thinking workers, and can yield more important results than ever before);—all expenses of issuing the first of the Fact-Sheets of Industry are being borne by The National Vulcanized Fibre Company and its various divisions and associated industries.

NATIONAL VULCANIZED FIBRE COMPANY
WILMINGTON, DELAWARE, U. S. A.

Volume Controls

TO vary the intensity of the faithful reproduction built into radio receivers without introducing noise or distortion, can only be accomplished by a careful and complete consideration of both mechanical and electrical features of the volume control.

Mechanically—The Centralab exclusive and patented rocking disc contact precludes any possibility of wear on the resistance material. This feature adds to the smoothness of operation since the contact shoe rides only on the disc. The shaft and bushing are completely insulated from the current carrying parts—eliminating any hand capacity when volume control is placed in a critical circuit.

Manufactured in three sizes
Standard
Junior
Midget
Also Double Standard and Double Junior

Electrically — Centralab engineers have evolved tapers of resistance that produce a smooth and gradual variation of volume. These tapers have been thoroughly tried and tested for each specific application for current carrying capacity and power dissipation.

Centralab volume controls have been specified by leading manufacturers because of their quality and ability to perform a specific duty—Vary the intensity of faithful reproduction—faithfully.

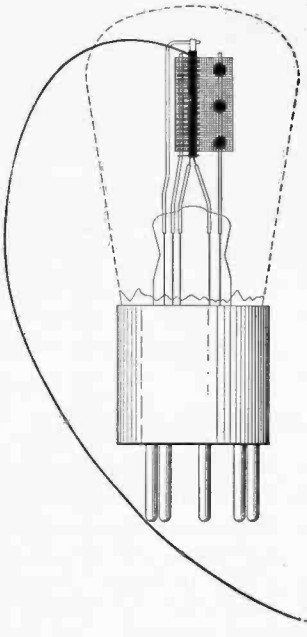
Write for full particulars of specific application.

Centralab
CENTRAL RADIO LABORATORIES
36 Keefe Ave. Milwaukee, Wis.

A CENTRALAB VOLUME CONTROL IMPROVES THE RADIO SET

Fused Pure Silica
Vitreosil

THE IDEAL INSULATION



PROGRESSIVE manufacturers, making the better kind of AC heater-type radio tubes use Vitreosil insulation for its freedom from gas and uniform wall which produces even heat distribution. It easily meets the thermal conditions of sudden heating and cooling, is mechanically strong, and available at low cost in single or multibore styles, and twin bore in either oval or circular cross section.

You can identify this Vitreosil product, illustrated herewith, by its smooth satin finish.

Let us send samples and quote on your requirements.

PURE FUSED SILICA
VITREOSIL
Reg'd Trade Mark
THE THERMAL SYNDICATE LTD
WALLSEND ON TYNE

THE THERMAL SYNDICATE, Ltd.

1716 Atlantic Avenue Brooklyn, New York

This packing slip found in every Dudlo shipping case carries the clock number of the final inspector . . . it places the definite responsibility for the accuracy and perfection of the contents of each case.

Definite Responsibility

Dudlo inspection is a definite protection to every user of Dudlo products. Final inspection and packing are *one operation* . . . for the inspectors themselves pack the cases as the coils are passed. No other hands touch them after your packing slip is signed, and the inspector is directly responsible for every coil passed.

Only the most experienced and competent employees are promoted to the inspection department, and their positions depend on their accuracy and dependability.

Dudlo coils *must meet your* specifications.

DUDLO

DUDLO MANUFACTURING COMPANY, FORT WAYNE, INDIANA
Division of General Cable Corporation

EVOLUTION

SCOVILL began the manufacture of radio condensers when the radio industry was in its infancy. It was brave pioneering back in those days of condenser development and had it not been for fundamental engineering science and manufacturing skill we feel sure that radio would just be emerging from swaddling clothes. The condenser is both the eye and the pulse of the set. There is no more graphic presentation to the engineering mind of Scovill's contributions to condenser development than to compare our first commercial effort with our product of today.

Scovill is proud of service in this direction and hopes to continue for many years its association with those leaders in the radio field who insist upon Scovill condensers.

SCOVILL

Established 1802

MANUFACTURING COMPANY

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NEW YORK
LOS ANGELES
PROVIDENCE
ATLANTA
CLEVELAND
SAN FRANCISCO

SCOVILL
MEMBER COPPER & BRASS RESEARCH ASSOCIATION

PHILADELPHIA
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BOSTON
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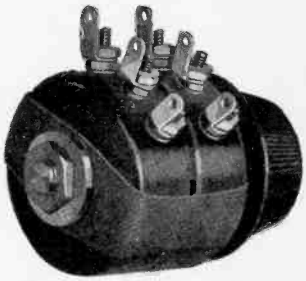
In Europe—THE HAGUE, HOLLAND

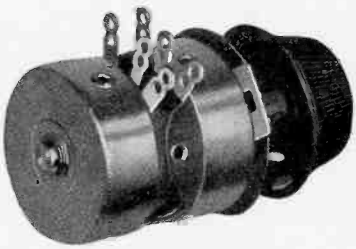
FROST-RADIO

offers manufacturers Volume Control Units of precision and utmost dependability

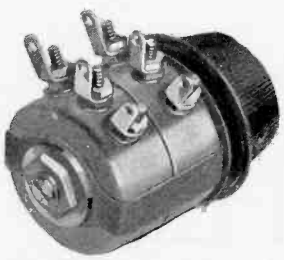


No. 2880-2880. Bakelite shell composition element only. Resistance range from 5,000 ohms to 1 megohm. All curves. Potentiometer or rheostat types. Units insulated from each other. Diameter, 1 1/2 in. Depth of shell, 1 1/8 in.

WHAT is it that every manufacturer seeks in a volume control? Isn't it first of all *precision workmanship* that insures absolute accuracy so that the unit will perform the duty assigned to it with certainty? And then isn't *dependability* next in importance? Summed up, these two essentials of a volume control are: To work perfectly, and to stand up. Frost Radio Volume Controls have both these requirements. In addition, they are non-inductive, unaffected by temperature changes, noiseless, wear-proof, smooth in operation, and made to fit any desired curve.



No. 200-200. Metal shell type wire wound resistors with resistances from 5 ohms to 10,000 ohms. Split windings. Rheostat or potentiometer types. Units insulated. Diameter, 1 7/16 in. Depth of shell, 1 1/2 in.



No. 590-590. Metal shell, composition element only. Resistances from 5,000 ohms to 1 megohm. All curves. Potentiometer or rheostat types. Units insulated from each other. Diameter, 1 5/16 in. Depth of shell, 1 1/8 in.

We are equipped to produce Frost Radio Volume Controls in either wire wound or carbon element type, clockwise or counter-clockwise knob rotation, and with absolute accuracy in all resistance gradations from 5 ohms to 1 megohm. Our service is unique, speedy and satisfying. Ask us to submit samples based on your particular specifications.

HERBERT H. FROST, Inc.
***Main Offices and Factory:* Elkhart, Ind.**
160 North La Salle Street, CHICAGO

The World's Largest Manufacturer of High Grade Variable Resistors

The Institute of Radio Engineers

Incorporated

33 West 39th Street, New York, N. Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

To the Board of Direction

Gentlemen:

I hereby make application for Associate membership in the Institute.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

.....

(Sign with pen)

.....

(Address for mail)

.....

(Date) (City and State)

References:

(Signature of references not required here)

Mr. ..... Mr. .....

Address ..... Address .....

Mr. ..... Mr. .....

Address ..... Address .....

Mr. .....

Address .....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

(Typewriting preferred in filling in this form) No.....

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

1 Name .....
(Give full name, last name first)

2 Present Occupation.....
(Title and Name of concern)

3 Permanent Home Address.....

4 Business Address.....

5 Place of Birth..... Date of Birth..... Age.....

6 Education .....

7 Degree .....
(college) (date received)

8 Training and Professional experience to date.....

NOTE: 1. Give location and dates. 2. In applying for admission to the grade of Associate, give briefly record of radio experience and present employment.

DATES HERE	

9 Specialty, if any.....

Receipt Acknowledged..... Elected..... Deferred.....
Grade..... Advised of Election..... This Record Filed.....

AEROVOX
BUILT BETTER
CONDENSERS AND RESISTORS

How Do You Buy Condensers?

MOST filter condensers, condenser blocks and bypass units are bought merely on the basis of price, voltage ratings and their ability to withstand ordinary short-time tests, without sufficient consideration to the fact that these are not dependable indicators of the ability of a condenser to stand up under all conditions of service, during the entire life of the receiver or power unit.

Nothing is apt to prove as costly as a cheaply made, over-rated condenser or resistor. Whether you are a manufacturer, professional set builder or experimenter, you cannot afford the high cost luxury of a cheap condenser or resistor.

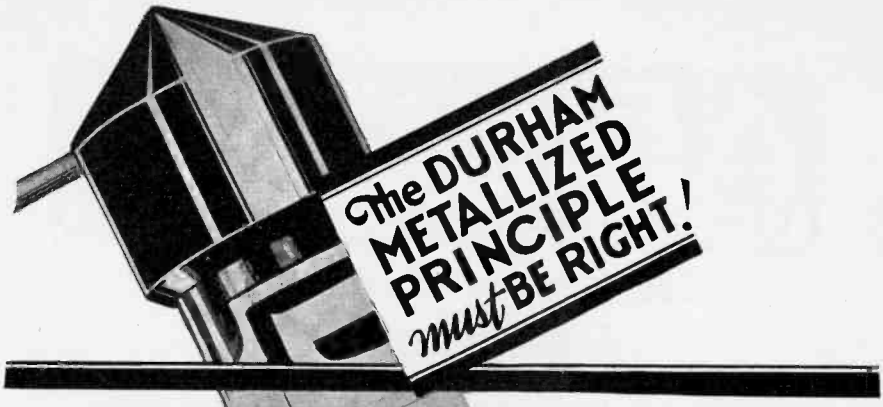
Aerovox condensers and resistors are conservatively rated and thoroughly tested. The Aerovox Wireless Corporation makes no secret of the Insulation Specifications of their filter condensers and filter condenser blocks. This information is contained in detail in the 1928-29 catalog.

The next time you are in the market for filter condensers or filter condenser blocks, make your comparison on the basis of Insulation Specifications. Aerovox condensers are not the most expensive, nor the cheapest, but they are the best that can be had at any price.

Send For Complete Catalog

Complete specifications of all Aerovox units, including insulation specifications of condensers, carrying capacities of resistors and all physical dimensions and list prices are contained in a fully illustrated 32-page catalog which will be sent free of charge on request.

AEROVOX WIRELESS CORP.
80 Washington Street, Brooklyn, N. Y.
PRODUCTS THAT ENDURE



A Million and a half used Monthly during 1929 in American Radio

To keep pace with 1930 receiver developments, Durham Metallized resistors and powerohms are now more accurate, have a greater power safety factor and can be obtained in even greater variety.

The advantages of the Durham Metallized principle have been proven by the millions of Durham resistors and powerohms now used by America's foremost manufacturers of radio receivers and allied products.

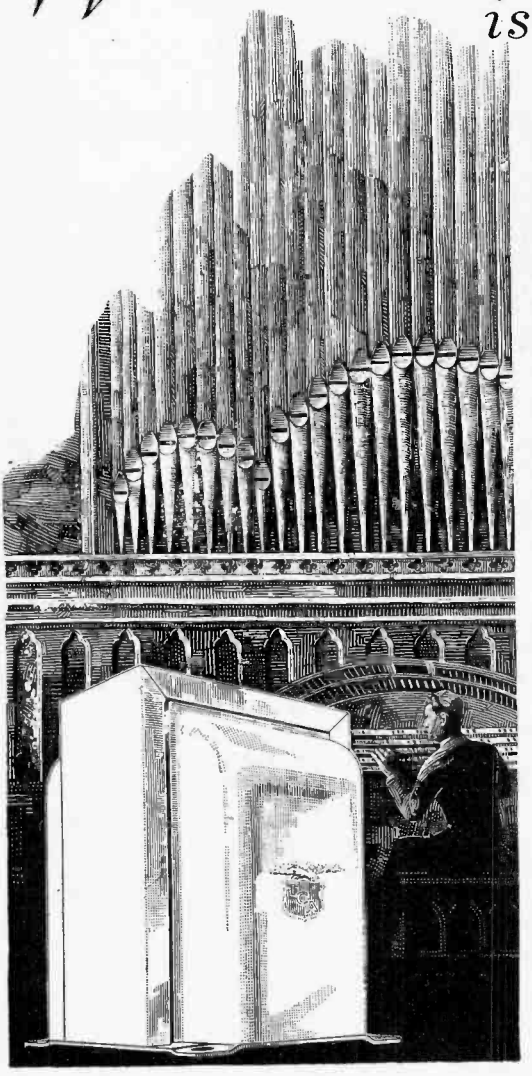
These units are now in standard production in all ratings, all types of tips for radio work.

Engineering data and samples for testing sent upon request. Please state ratings required.

International Resistance Company

2006 Chestnut Street, Philadelphia, Pa.

When real **TONE-RICHNESS** *is required*



TRANSFORMER amplification is by all odds, and for many reasons, the favorite. True in tone over the full musical range, inexpensive, trouble-free, and enjoying the full confidence of a discerning public.

Transformers make the set.

The design and construction of transformers determine the quality of reception.

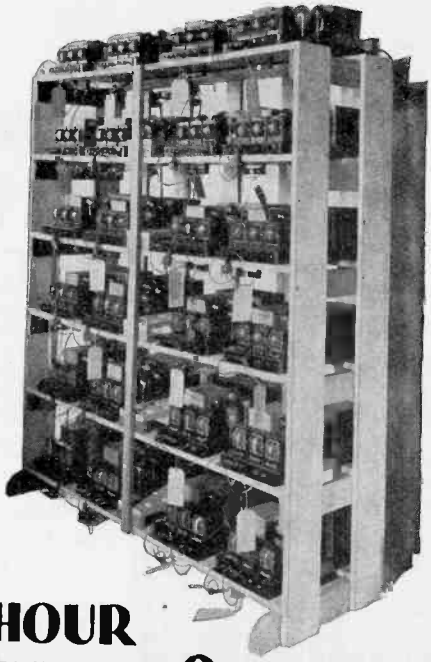
With the co-operation of the T-C-A engineering staff, you can be sure of the highest attainable results.

Complete manufacture and controlled quantity production have made T-C-A the favorite on the nation's finest sets. Audios . . Power-transformers . . Chokes . . Power Packs . . Dynamic Speakers.

TRANSFORMER CORPORATION OF AMERICA
2301-2319 SOUTH KEELER AVENUE
CHICAGO, ILLINOIS

TCA

POWER UNITS
THAT STAY SOLD



14 HOUR CONTINUOUS OPERATION TEST

EACH component part of every Operadio Power Unit is *individually tested,* both electrically and, where applicable, for tone, before being released to the Assembly Department. After assembly, each unit is given *three separate and distinct tests* for continuity and tone reproduction. After this, it is hooked up and run under conditions exactly as they would be in actual operation *for a period of fourteen hours.* The illustration shows this test.

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OPERADIO MFG. COMPANY
St. Charles, Illinois

OPERADIO

Airplane Floyd Bennett, which carried the Byrd party safely to and from the South Pole.

The First Radio Message from the South Pole

— *flashed over antennae equipped with* PYREX *Insulators*

Four PYREX Insulators like this are used on the antennae of the Floyd Bennett.

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Triumphant at last, after months of preparation, Commander Byrd has flown over the South Pole. From his airplane, the Floyd Bennett, he flashed the news by radio while flying directly over the Pole.

On all his base ship, airplane, and portable stations Commander Byrd uses PYREX radio insulators, exclusively. They have well earned his confidence. The Commander's radio message that he was flying over the North Pole, his distance record for low-wave length signals, his reports from the transatlantic airplane, America—all were sent over PYREX insulator equipped antennae.

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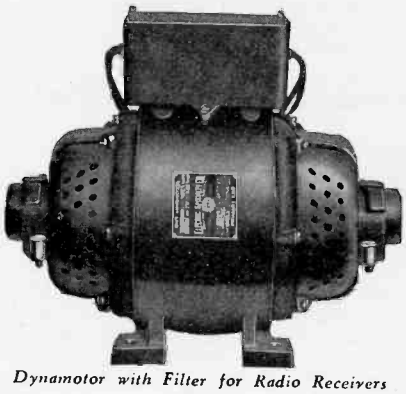

Dynamotor with Filter for Radio Receivers

"ESCO" manufacturers for regular stock four sizes of dynamotors known as RL2 (75 watts) RL4 (160 watts) LF3 (350 watts) and LF5 (550 watts)—These are wound for 32 volt, 110 volt, or 220 volt. Special voltages and sizes made to order. Prompt delivery and low prices. Dynamotors require no starting controllers.

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All machines are equipped with "ESCO" filter specially designed for sensitive radio sets—The filtration is as near perfect as scientific research can develop.

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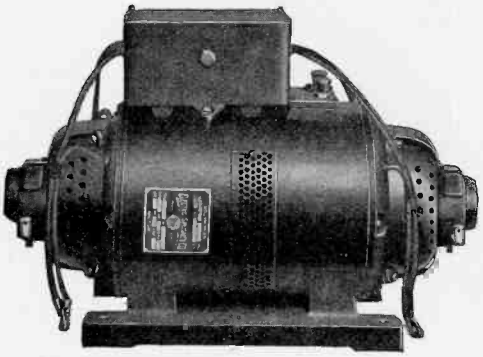

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Three styles of Institute emblems, appropriately colored to indicate the various grades of membership in the Institute, are available. The approximate size of each emblem is that of the illustrations.

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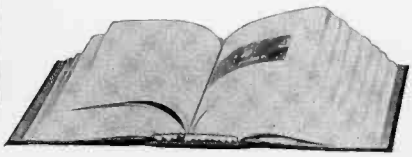

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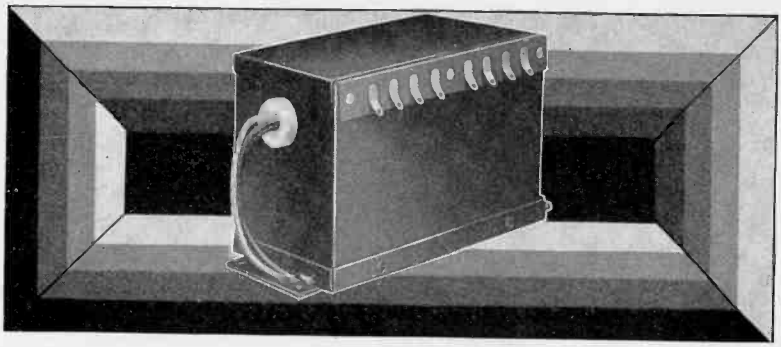

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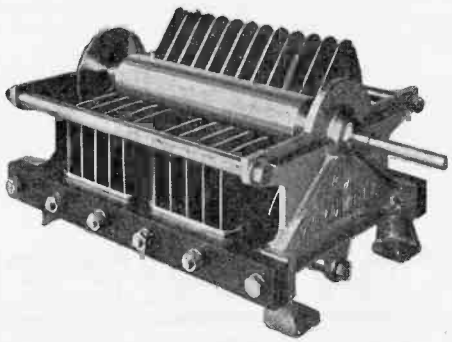

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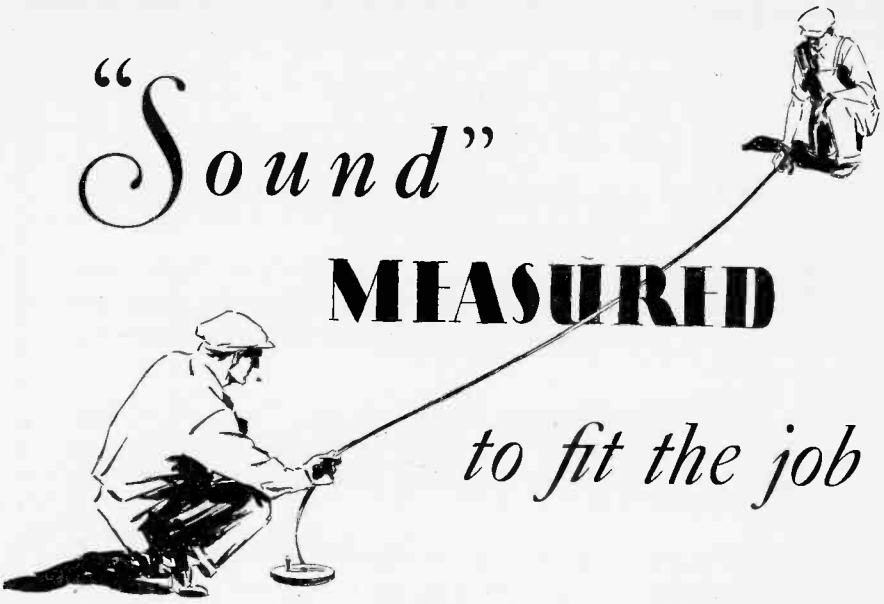

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The contents of each issue can be found in the 1914-1926 Index and in the 1929 Year Book (for the years 1927-28).

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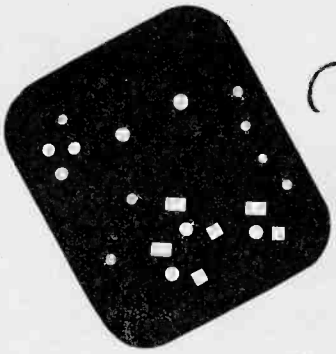

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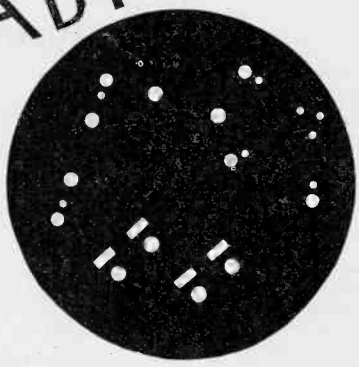

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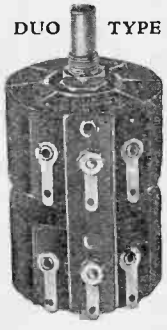

Please do not confuse this device with carbon paper, graphited fibre, or other devices the current-handling capacity of which is usually insufficient for continuous, present-day radio circuit use. Do not confuse it with other wire-wound devices, usually avoided because of the disagreeable grating, grinding sounds made during adjustment. The Wire-Wound Volume Control Clarostat turns with a smooth, velvety, really delightful motion. And it is as silent as the Sphinx, even in the most critical, high-gain circuits.

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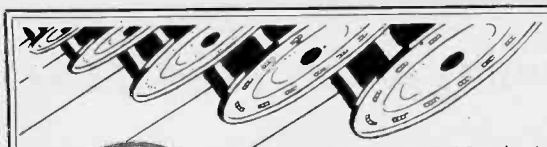

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GILBY WIRE COMPANY

Wilbur B. Driver, President

NEWARK, NEW JERSEY

STUDY the Quality of this *FILAMENT*

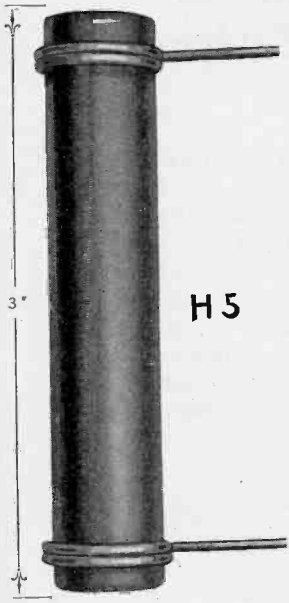
PRECISION
(uncoated)
FILAMENT
For Radio Tubes

✓ *Free from Surface Impurities*
✓ *Correctly Spooled*
✓ *Accurate*
✓ *Uniform size, weight and resistance*

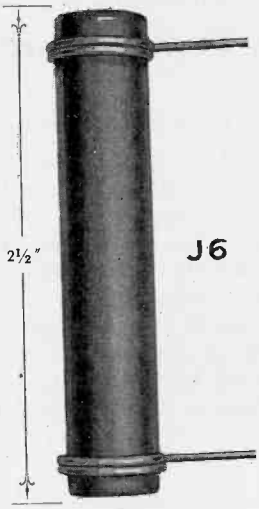
SIGMUND COHN

44 Gold Street — New York

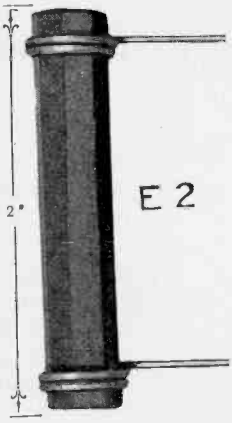
Continental Resistors



5 Watts



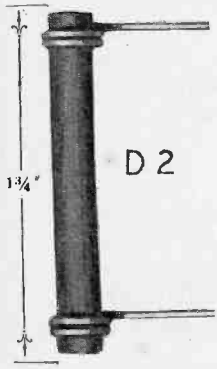
3½ Watts



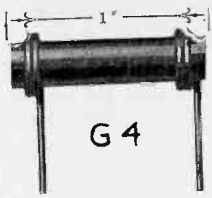
2 Watts

CHARACTERISTICS:

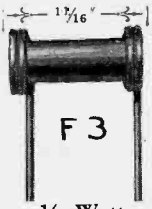
NOISELESS
RESISTANCE CONSTANT
SMALL TEMPERATURE COEFFICIENT
RUGGED
FIRMLY SOLDERED TERMINALS
DEPENDABLE
COLOR CODED



1 Watt



¾ Watt



½ Watt

Write for Information and Prices

CONTINENTAL CARBON INC.
WEST PARK, CLEVELAND, OHIO

Piezo Electric Crystals and Constant Temperature Equipment

Piezo Electric Crystals:

We are prepared to grind Piezo Electric Crystals for POWER use to your assigned frequency in the 550 to 1500 KC band, *accurate to plus or minus 500 cycles* for $55.00 fully mounted. Crystals for use in the HIGH FREQUENCY BROADCAST BAND (4000 to 6000 KC) for POWER use, accurate to plus or minus .03% of your assigned frequency, fully mounted, $85.00. In ordering please specify type of tube used, plate voltage and operating temperature. All crystals guaranteed with respect to output and accuracy of frequency. Deliveries can be made within three days after receipt of order.

Constant Temperature Equipment

In order to maintain the frequency of your crystal controlled transmitter to a high degree of constancy, a high grade temperature control unit is required to keep the temperature of the crystal constant. Our unit is solving the problem of keeping the frequency within the 50 cycle variation limits. Our heater unit maintains the temperature of the crystals constant to BETTER THAN A TENTH OF ONE DEGREE CENTIGRADE; is made of the finest materials known for each specific purpose and is absolutely guaranteed. Price $250.00. Further details sent upon request.

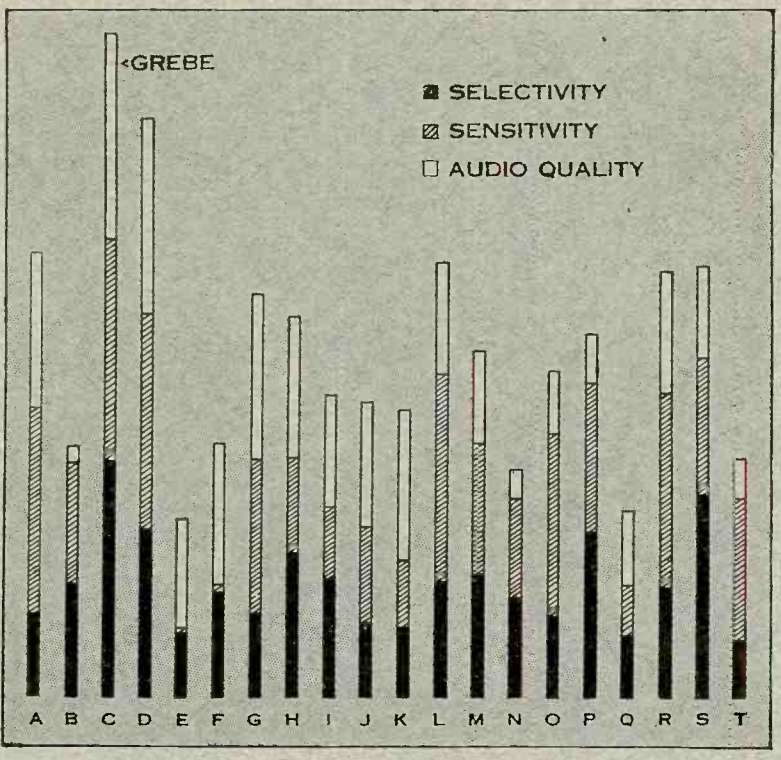
Low Frequency Standards:

We have a limited quantity of material for grinding low frequency standard crystals. We can grind them as low as *15,000 cycles.* These crystals will be ground to your specified frequency accurate to ONE HUNDREDTH OF ONE PER CENT. Prices quoted upon receipt of your specifications.

Scientific Radio Service

"The crystal specialists"

P. O. Box 86 Dept. R6 Mount Rainier, Md.



Measurements of band width at 1400 K.C.—average microvolt per meter input at 1400—1000—600 K.C. and total decibels audio amplifier loss relative to 500 cycles (at 60 and 5000 cycles) form the basis for a comparison with 20 sets measured for the same qualities. The Grebe measured 43 K.C. width at 1400 K.C. with 100 times input. It measures an average of 1.75 microvolts per meter input for standard output and it shows a total loss of 5.5 D. B. (4.5 D. B. at 60 cycles and 1 D. B. at 5000 cycles) from detector to voice coil. Translated in the new Grebe rating in % this respectively gives 93, 88 and 82%. The equation for selectivity rating is $\frac{40}{\text{band width.}}$ Sensitivity $1-\frac{1}{2}\log(S)$. Audio $\frac{30-\text{sum D. B.}}{30}$

Grebe radio

SUPER-SYNCHROPHASE

A. H. GREBE & CO., INC., Richmond Hill, N. Y.

Western Branch: 443 So. San Pedro Street, Los Angeles, California

Temperature-Control Boxes

Type 547-A Temperature Control Box

TYPE 547-A

Controls to 0.1 degrees C.

Mercury-type thermoregulator, adjustable for any operating temperature between 40 degrees and 60 degrees C.

Price $150.00.

TYPE 547-B

Controls to 1.0 degrees C.

Bi-metallic-type thermoregulator, adjustable while operating for any temperature between 40 degrees and 60 degrees C.

Price $150.44.

A TEMPERATURE-CONTROL box worthy of the name must maintain its temperature within specified limits over a wide variation in the temperature of the room in which it operates. General Radio temperature-control devices will remain within their specified limits for room temperature variations of ±20 degrees F., a range of 40 degrees. They are practically independent of the weather and the janitor's ability to keep constant the temperature of the operating room.

The TYPE 547 Temperature Control Boxes are made in the two types listed above but the second one is recommended only for use where it is necessary to adjust the operating temperature while the unit is in operation.

Both are encased in walnut cabinets within which are arranged (in order) a balsa wood insulating layer, the heaters (on all six faces), an aluminum distributing layer, an asbestos pressboard attenuation layer, and a second casing of aluminum which forms the temperature-controlled chamber.

GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS
British Branch: 76 Old Hall Street, Liverpool

GENERAL RADIO INSTRUMENTS

FOR MEASURING ELECTRICAL QUANTITIES AT ALL FREQUENCIES

GR

STANDARD AND SPECIAL ITEMS FOR LABORATORY AND INDUSTRIAL USE

GEORGE BANTA PUBLISHING COMPANY; MENASHA, WISCONSIN